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Effect of mass flow on stack eductor performance.

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NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

EFFECT OF MASS FLOW ON STACK
EDUCTOR PERFORMANCE

by

Richard W. White

June 1984

Thesis Advisor: P. F. Pucci

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Effect of Mass Flow on Stack Eductor Performance

by

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Lieutenant, United States Navy
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GREEK LETTER SYMBOLS

γ - ratio of specific heats for air

μ - absolute viscosity, $lbf\text{-}sec/ft^2$

ρ - density, lbm/ft^3

ϕ - "function of"

ENGLISH LETTER SYMBOLS

A - area, in^2, ft^2

B - atmospheric pressure, in Hg

c - sonic velocity, ft/sec

C - coefficient of discharge

D - diameter, in

DELPN - pressure drop across entrance nozzles, in H_2O

DELPU - pressure drop across U-tube assembly, in H_2O

f - skin friction factor

F_{fr} - wall skin friction force, lbf

g - Newton's Second Law proportionality constant

$$g = 32.174 \ lbm\text{-}ft/lbf\text{-}sec^2$$

h - enthalpy, Btu/lbm

l - length, in

L - mixing stack length, in

P - pressure, in H_2O

PMS - mixing stack pressure, in H_2O

PNH - inlet air pressure, in H_2O

PPLN - secondary plenum pressure drop, in H_2O

PUPT - uptake pressure, in H_2O

r - radial distance from mixing stack centerline, in

R - gas constant for air, R = 53.34 ft-lbf/lbm R

ROTA - fuel rotameter reading

s - entropy, Btu/lbm-R

S - mixing stack standoff distance, in

T - temperature, ^oF, R

TAMB(R) - ambient temperature, ^oF (R)

TBURN(R) - burner temperature, ^oF (R)

TEP - exit plane temperature, ^oF

TNH(R) - inlet air temperature, ^oF (R)

TUPT(R) - uptake temperature, ^oF (R)

u - internal energy, Btu/lbm

U - velocity, ft/sec

UM - uptake average velocity, ft/sec

UP - nozzle exit velocity, ft/sec

UU - primary flow velocity in uptake, ft/sec

v - specific volume, ft^3/lbm

W - mass flow rate, lbm/sec

WF - fuel flow rate, lbm/sec

WP - primary flow rate, lbm/sec

WS - secondary flow rate, lbm/sec

WPA - primary air flow rate, lbm/sec

DIMENSIONLESS GROUPINGS

A^* - secondary flow area to primary flow area ratio

A_t^* - tertiary flow area to primary flow area ratio

K_e - kinetic energy correction factor

K_m - mixing stack exit momentum correction factor

K_p - primary nozzle exit momentum correction factor

M,UMACH - Mach number

P^* - secondary flow pressure coefficient

P_t^* - tertiary flow pressure coefficient

PMS - mixing stack pressure coefficient

Re - Reynolds number

T^* - secondary flow to primary flow absolute temperature ratio

T_t^* - tertiary flow to primary flow absolute temperature ratio

W^* - secondary to primary mass flow rate ratio

W_t^* - tertiary to primary mass flow rate ratio

SUBSCRIPTS

0 - measurement plenum section

1 - primary nozzle exit section

2 - mixing stack exit section

a - atmospheric

b - burner

p - primary

s - secondary

t - tertiary

u - uptake

w - mixing stack wall

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I. INTRODUCTION

The advent of the marine gas turbine provided surface ships a propulsion plant offering mechanical reliability and flexibility of operation not found in conventional steam plants. Several problems, however, have been afforded the surface vessel via this technology. Mass flow rates four to five times their steam counterpart and exhaust temperatures in the vicinity of 950°F have created considerable interest and subsequent research.

Significant research conducted at the Naval Postgraduate School has proved the effectiveness of the multiply-shrouded eductor system in reducing exhaust temperatures. This is of extreme interest in an at sea environment of IR (infra-red) technology. These eductors induce secondary and tertiary air under turbulent conditions into the primary flow. Significant temperature reductions have been realized utilizing this technique and, notably, without unacceptable engine performance degradation.

This research will continue to investigate design improvements to eductor geometry and also investigate the effect of primary mass flow upon eductor performance. These two objectives, along with the utilization of a computer aided data acquisition system are the salient features of this research.

II. BACKGROUND

Charwat [Ref. 1] at the University of California at Los Angeles provided a solid wall mixing stack gas eductor design for incorporation in the DD-963 class design. The solid wall design relied on the length of the mixing stack for total mixing. In 1976 research began at the Naval Postgraduate School. Initial investigations determined the effect of various parameters on the performance of the gas eductor. Eductor size and weight reduction and performance improvement have been the primary objectives of subsequent research.

A. NAVAL POSTGRADUATE TEST FACILITIES

Two test facilities exist at the Naval Postgraduate School. The "cold flow" facility affords timely evaluation of varied eductor configurations due to relatively low temperatures allowing ease in model fabrication and data collection.

Models are tested under actual operating conditions at the "hot flow" facility. This facility can verify cold flow data as well as provide essential data on exhaust temperatures and mixing stack surface (film) temperatures.

B. INITIAL RESEARCH

Pucci [Ref. 2] developed a one dimensional gas eductor model. Utilizing this model, Ellin [Ref. 3] verified a correlation existing between dimensionless groupings representing pressure depression in and induced flow from an eductor's secondary environment.

Moss [Ref. 4] and Harrell [Ref. 5] followed Ellin's work on the cold flow facility. In order to accurately verify the relationship determined by Ellin, it was recommended that actual operating conditions were essential for complete testing of eductor models. Ross [Ref. 6] subsequently completed the construction, calibration, and test verification of the hot flow test facility. Initial hot flow testing was accomplished by Welch [Ref. 7] utilizing a 4 nozzle, solid walled mixing stack eductor.

C. SUBSEQUENT RESEARCH

Initial research highlighted significant pressure depression within the length of the solid walled mixing stack. It was hypothesized that the introduction of tertiary air along the mixing stack would enhance film cooling effects on eductor surface temperatures.

The use of cooling ports along the mixing stack and the shroud around the mixing stack was first investigated by Staehli and Lemke [Ref. 8]. Hill [Ref. 9] tested a slotted mixing stack under actual operating conditions. Excellent hot flow results using multiply shrouded eductors were reported by Eick [Ref. 10] and Kavalis [Ref. 11]. Staples [Ref. 12] confirmed research conducted by Pritchard [Ref. 13] and additionally examined the effects of turbulent cross flow on eductor performance.

D. CURRENT RESEARCH

Previous researchers collected all temperature and pressure data at the hot flow facility manually without the utilization of computer technology. Consequently a computer aided data acquisition system was designed, programmed, and implemented at the facility. Utilizing Staples' Model A Modified [Ref. 12] testing and verification of the data collection system was accomplished. The model was further modified and the effect of primary air flow variance simulating varying engine exhaust conditions was investigated.

III. THEORY AND MODELING

Simplicity is the major benefit of an eductor, no matter what its' application. The ability of a jet of primary fluid to pump secondary fluid has been proven time after time in eductor design. Lacking moving parts, the eductor is a maintenance luxury. This very fact lends the eductor to application in marine gas turbine exhaust stacks, which are normally not readily accessible during engine operations. Hot primary fluid pumps cooler secondary fluid, and in some cases, tertiary fluid, achieving noticeably lower exhaust temperatures.

In this and previous research Mach number similitude has been chosen between model and prototype. Non-dimensionalization of eductor performance parameters has facilitated comparative research and is therefore utilized in this research. A one-dimensional analysis of the simple eductor equation reveals all coefficients utilized.

A. MODELING TECHNIQUE

Prior research has proven that the air flow in the mixing stack of the model is turbulent with Reynolds' number greater than 10^5. Viscous forces are consequently overshadowed by kinetic and internal energy terms and shear interaction is dominated by momentum exchange. Mach number, therefore, can be shown to exist as the prominent parameter vice Reynolds' number and is chosen as an accurate correlation between model and prototype.

B. ONE DIMENSIONAL ANALYSIS OF A SIMPLE EDUCTOR

One analysis technique, inherently complex, of an eductor concerns itself with the mixing of primary and secondary air internal to the mixing stack. A simpler analysis ignores this mixing and has been completely outlined in [Ref. 2] and [Ref. 3]. A repetitive detailed derivation is not considered prudent, hence only assumptions and parameters will be discussed. Simultaneous solution of the equations of continuity, energy, and momentum coupled with the equations of state allow analysis of the simple eductor system shown schematically in (Fig. 1).

Simplifying idealizations are as follows:

1) Steady and incompressible flow exists within the mixing stack.

2) Uniform static pressure exists across the entrance and exit planes.

3) Flow from the tertiary plenum to the minimum area at Section 2 is isentropic, with irreversible adiabatic mixing between Sections 2 and 3.

4) Adiabatic flow exists throughout the eductor with isentropic flow of the secondary stream from Section 0 to Section 1 and irreversible adiabatic mixing of the primary and secondary streams occurring within the mixing stack.

5) At Section 1 the primary flow velocity U_p and temperature T_p is uniform across the stream as is the secondary flow velocity U_s and temperature T_s however U_p and U_s are not equal and neither are T_p and T_s.

6) Primary and secondary flows behave as perfect gases.

7) At Section 2 an average mixing velocity, U_x, and temperature, T_x, exist.

8) A non-dimensional momentum correction factor, K_m, relating the actual momentum rate to the pseudo-rate and a non-dimensional kinetic energy correction factor, K_e, relating the actual kinetic energy to the pseudo-rate, both of which are based on the bulk average velocity and density, account for the incomplete mixing of primary, secondary, and tertiary air within the mixing stack.

9) Gravitational potential energy variations are neglected.

10) The bulk average flow velocity, U_m, and the mixing stack wall area A, serve as the basis for the conventional pipe friction factor term which accounts for wall friction within the mixing stack.

11) Pressure changes P_{os} to P_1, P_0 to P_2, P_1 to P_2, and P_2 to P_3 ($=P_a$) are small compared with static pressure, so that gas density is essentially dependent upon temperature and atmospheric pressure.

The following parameters, specified by Staples [Ref. 12], are reiterated here for simplicity, as they will be utilized in the ensuing explanation.

A_f/A_m ratio of primary flow area to mixing stack cross section area

A_w/A_m ratio of wall friction area to mixing stack cross section area

K_p primary mixing momentum correction factor

K_m mixed flow momentum correction factor

f wall friction factor

Continuity and the conservation of mass principle yields (ref. Fig.1)

$$\rho_M U_M A_M = \rho_P U_P A_P + \rho_s U_s A_s + \rho_t U_t A_t \qquad \text{(eqn 3.1)}$$

and defining:

$$\begin{aligned} W_M &= \rho_M U_M A_M \\ W_S &= \rho_s U_s A_S \\ W_P &= \rho_P U_P A_P \\ W_t &= \rho_t U_t A_t \end{aligned} \qquad \text{(eqn 3.2)}$$

Combining eqn (3.1) and (3.2) and utilizing assumptions (2) and (5) above the bulk average velocity at the mixing stack, U_m, is

$$U_M = \frac{W_S + W_t + W_P}{\rho_M A_M} \qquad \text{(eqn 3.3)}$$

A_m is fixed by geometry and

$$\rho_M = \frac{P_a}{R T_M} \qquad \text{(eqn 3.4)}$$

where T_m is the bulk average temperature calculated from equation (3.11). Fluid mechanics reveals the momentum equation derived from Newton's Laws and is the conventional force and momentum-balance equation.

$$K_P\left(\frac{W_P U_P}{g_c}\right)+\left(\frac{W_S U_S}{g_c}\right)+\left(\frac{W_t U_t}{g_c}\right)+P_1 A_1 = K_M\left(\frac{W_M U_M}{g_c}\right)+P_2 A_2 + F_{fr} \qquad \text{(eqn 3.5)}$$

The primary mixing momentum correction factor, K_p, is defined similarly to K_m (eqn 3.6), and utilizing idealization (5), is set equal to unity. It is included here for purposes of completeness only. The mixing stack exit momentum correction factor is defined by the relation

$$K_M = \frac{1}{W_M U_M^2}\int_0^{A_M} U_S^2 \rho_3 \, dA \qquad \text{(eqn 3.6)}$$

where U_3 is defined by equation (3.3). Utilizing idealization (10), the wall skin friction force, F_{fr}, is related to the flow stream by

$$F_{fr} = f A_W\left(\frac{U_M^2 \rho_M}{2\ g_c}\right) \qquad \text{(eqn 3.7)}$$

Defining the Reynold's Number as

$$Re_M = \frac{\rho_M U_M D_M}{\mu_M} \qquad \text{(eqn 3.8)}$$

the friction factor for turbulent can be calculated as

$$f = 0.046 \left(R_{e_M} \right)^{-0.2} \quad \text{(eqn 3.9)}$$

Applying idealization (9) and the conservation of energy principle to the steady flow system in the mixing stack,

$$W_P \left(h_P + \frac{U_P^2}{2 g_c} \right) + W_S \left(h_s + \frac{U_S^2}{2 g_c} \right) + \left(h_t + \frac{U_t^2}{2 g_c} \right) = W_M \left(h_M + \frac{K_e U_M^2}{2 g_c} \right) \quad \text{(eqn 3.10)}$$

where, K_e, the kinetic energy correction factor is defined as

$$K_e = \frac{1}{W_M U_M^2} \int_0^{A_M} U_3^2 \rho_3 \, dA \quad \text{(eqn 3.11)}$$

It may be demonstrated that the kinetic energy terms may be neglected in the evaluation of the mixed mean flow temperature, T_m, to yield

$$h_M = \frac{1}{W_M} \left(h_P W_P + h_S W_S + h_t W_t \right) \quad \text{(eqn 3.12)}$$

where $T_m = \phi(h_m)$ only, using idealization (6).

The energy equation for the isentropic secondary air flow from the plenum to the mixing stack entrance reduces to

$$\frac{P_{os} - P_S}{\rho_s} = \frac{U_S^2}{2 g_c} \quad \text{(eqn 3.13)}$$

and similarly, for the tertiary air flow the energy equation becomes

$$\frac{P_{ot} - P_t}{\rho_t} = \frac{U_t^2}{2 g_c} \qquad \text{(eqn 3.14)}$$

Combining these few equations yields the vacuum produced by the eductor in the secondary or tertiary plenums. Again referring to Figure 1, the secondary plenum vacuum is

$$P_a - P_{os} = \frac{1}{g_c A_M}\left[K_P\left(\frac{W_P^2}{A_P \rho_P}\right) + \frac{W_s^2}{A_s \rho_s}\left(1 - \frac{A_M}{2A_s}\right) + \frac{W_t^2}{A_t \rho_t} - \frac{W_M^2}{A_M \rho_M}\left(K_M + \frac{f A_W}{2 A_M}\right)\right] \qquad \text{(eqn 3.15)}$$

and the tertiary plenum vacuum is

$$P_a - P_{ot} = \frac{1}{g_c A_M}\left[K_2 \frac{(W_P + W_s)^2}{A_M \rho_2} + \frac{W_t^2}{A_t \rho_t}\left(1 - \frac{A_M}{2A_t}\right) - K_M\left(\frac{W_M^2}{\rho_M A_M}\right)\right] \qquad \text{(eqn 3.16)}$$

where the primary flow is now defined as the sum of the primary and secondary flows and K_2 is the momentum correction factor at Section 2.

C. NON-DIMENSIONAL FORM OF THE SIMPLE EDUCTOR EQUATION

Equations (3.15) and (3.16) have been normalized utilizing the following parameters to achieve satisfaction of the criteria of geometrically similar flows.

$$P^* = \frac{\dfrac{P_a - P_{os}}{\rho_s}}{U_P^2/2g_c}$$

a pressure coefficient comparing the secondary flow pumped head $(P_a - P_{os})$ to the primary flow driving head $(U_p^2/2g_c)$

$$P_t^* = \frac{\frac{P_a - P_{ot}}{\rho_t}}{U_p^2/2g_c}$$ a pressure coefficient comparing the tertiary flow pumped head (P_a-Pot) to the primary flow driving head ($U_p^2/2g_c$)

$$W^* = \frac{W_s}{W_p}$$ secondary to primary mass flow rate ratio

$$W_t^* = \frac{W_t}{W_p}$$ tertiary to primary mass flow rate ratio

$$T^* = \frac{T_s}{T_p}$$ secondary to primary absolute temperature ratio

$$T_t^* = \frac{T_t}{T_p}$$ tertiary to primary absolute temperature ratio

$$\rho_s^* = \frac{\rho_s}{\rho_p}$$ secondary to primary flow density ratio. Since the fluids are modeled as perfect gases,

$$\rho_s^* = \frac{T_p}{T_s} = \frac{1}{T^*}$$

$$\rho_t^* = \frac{\rho_t}{\rho_p}$$ tertiary to primary flow density ratio. Again, due to the perfect gas theory,

$$\rho_t^* = \frac{T_p}{T_t} = \frac{1}{T_t^*}$$

$$A_s^* = \frac{A_s}{A_p}$$ secondary flow area to primary flow area ratio

$$A_t^* = \frac{A_t}{A_p}$$ tertiary flow area to primary flow area ratio

Equations (3.15) and (3.16) may now be written non-dimensional form.

$$\frac{P^*}{T^*} = \frac{2A_P}{A_M}\left[\left(K_P - \frac{A_P}{A_M}\beta\right) - W^*(1+T^*)\frac{A_P}{A_M}\beta + \frac{W_t^{*2} T_t^*}{A_t^*} + W^{*2}T^*\left(\frac{1}{A^*}\left(1-\frac{A_M}{2A^*A_P}\right) - \frac{A_P}{A_M}\beta\right)\right] \quad \text{(eqn 3.17)}$$

where

$$\beta = K_M + \frac{f}{2}\ \frac{A_W}{A_M} \quad \text{(eqn 3.18)}$$

This may be rewritten as

$$\frac{P^*}{T^*} = C_1 + C_2 W^*(1+T^*) + C_3 W^{*2} T^* + C_4 W_t^{*2} T_t^* \quad \text{(eqn 3.19)}$$

where

$$C_1 = 2\frac{A_P}{A_M}\left(K_P - \frac{A_P}{A_M}\beta\right) \quad \text{(eqn 3.20)}$$

$$C_2 = -2\left(\frac{A_P}{A_M}\right)^2\beta \quad \text{(eqn 3.21)}$$

$$C_3 = 2\frac{A_P}{A_M}\left[\frac{1}{A^*}\left(1-\frac{A_M}{2A^*A_P}\right)\beta - \frac{A_P}{A_M}\beta\right] \quad \text{(eqn 3.22)}$$

$$C_4 = \frac{1}{A_t^*} \quad \text{(eqn 3.23)}$$

Previous research has utilized two additional parameters to corrolate static pressure distribution along the length of the mixing stack.

X/D	axial distance from the mixing stack entrance to mixing stack diameter ratio

$$PMS^* = \frac{\frac{PMS}{\rho_s}}{\frac{U_p^2}{2g_c}}$$

secondary flow pumping head (PMS/ρ_s) to the primary flow driving head ($U_p^2/2g_c$) ratio, where PMS = static pressure along the mixing stack length

D. EXPERIMENTAL CORRELATION

Ellin [Ref. 3] and Moss [Ref. 4] confirmed that the correlation of P*, T*, and W* is of the form

$$P^*/T^* = W^* \, T^{**n} \qquad \text{(eqn 3.24)}$$

Ellin gives the detail of this formulation as well as determining a numeric value of 0.44 for n. Utilizing the equation and plotting P*/T* as a function of $W^*T^{**.44}$ experimental data is reduced yielding the gas eductor's characteristic pumping curve. Using Figure 38 as an example, data in region 1 is taken with the majority of the ASME nozzles closed. As more of the nozzles are opened region 2 is entered where approximately half of the nozzles are open. In region 3 the model is open to the atmosphere and data scatter increased. Using the data taken in regions 1, 2, and 3 and assuming that the model characteristics will not vary the point of zero intercept is extrapolated (point 4). At this point the actual operating point of the shipboard eductor is reached. The pumping coefficient is here in defined as this intercept, i.e., the value of $W^*T^{**.44}$ when P*/T* equals zero.

IV. EXPERIMENTAL APPARATUS

Ross [Ref. 6] designed, procured, and installed the hot flow facility utilized in this and previous research. Combustion air is supplied by a three stage Carrier Centrifugal Air Compressor located in building 230 of the Naval Postgraduate School Annex. The actual combustion gas generator and test facility is located in building 249. Appendix B details instructions for safe and proper operation of the compressor and gas generator.

A. COMBUSTOR AIR PATH

Compressed air is piped underground from the compressor in building 230 to the inlet of the test facility. The air enters via an eight inch vertical standpipe (Fig. 13) containing a butterfly valve, normally closed, in parallel with a remotely operated globe valve. A "T" connection at the top of this pipe directs the flow to either the combustion gas generator or to a short section of pipe utilized by the Aeronautical Engineering Department. An eight to four inch reducer or entrance nozzle is downstream of the "T", located just before the burner section. The flow characteristics of this non-standard nozzle were determined by Staples [Ref. 12]. A linear relation between pressure produce and mass flow rate of air was determined. The data collected by

Staples is presented in Table VII and shown graphically in Figure 35. Flowing through a manual isolation valve, the air then enters a splitter section.

In the splitter section air is either sent to the combustor section or directly to the mixing section. The amount of air flow sent in either direction is controlled by the motor operated burner air control valve and the motor operated cooling air bypass valve respectively. The flow characteristics of the U-tube leading to the combustor section were determined by Ross and are listed in [Ref. 6]. A swirl is physically introduced to the cooling air inside the nozzle box to counter that produced by the nozzle. Hot gases from the combustion section enter the mixing section via the burner nozzles and the resulting counter-rotating flow produces rapid and efficient mixing. A flow straightener and an uptake section then deliver the gas to the primary nozzles and ultimately the atmosphere.

B. FUEL SYSTEM

1. System Description

A 55 gallon drum mounted on an elevating stand (Fig. 21) external to building 249 serves as the system fuel reservoir. From this tank fuel flows to a bulkhead isolation valve inside the building after passing through a tank isolation valve and a sediment collector. Fuel temperature is measured at the bulkhead isolation valve. A flow measuring rotameter and a fuel filter direct the flow to a 24V DC positive displacement motor driven fuel supply pump. Normal fuel supply pressure is 14-16 psig.

The supply pump provides suction head to the high pressure fuel pump. An external recirculation line is provided as the HP pump has no internal bypass. A needle valve in this recirculation line controls the pump discharge pressure and therefore the burner fuel supply. A system drain valve and a manual discharge valve are located downstream of the HP pump (Fig. 23). Piping carries the fuel from the discharge of the HP pump to the combustor inlet solenoid.

2. <u>Fuel Flow Rate Calibration, Measurement, and Control</u>

Fuel flow rate is measured via a Fischer Porter Model 10A3565A rotameter. Calibration was accomplished on site using the fuel supply pump to deliver fuel to a container of known weight for a specific interval of time. A scale was used to weigh the "full" container and flow rate calculated. A needle valve was used to control pump discharge. Rotameter calibration data is listed in Table I. Figure 34 plots the flow rate verses rotameter reading. An HP15C calculator linear regression scheme resulted in the following expression

$$WF = -3.0904 + .4014*ROTA \qquad \text{(eqn 4.1)}$$

A fuel control valve located at the control station is utilized by the operator to select the desired fuel flow rate. A needle valve located near the HP pump is installed in parallel with the control valve and control valve sensitivity as well as assuring continuous flow through the pump. Procedures for setting the needle valve are outlined in Appendix B. When properly adjusted the needle valve allows operator controled fuel pressure from 80 to 350 psig, accurate to approximately 5 psig.

C. MEASUREMENT PLENUM

1. Plenum Seals

The rear wall seal is a diaphragm seal made of rubberized fabric. A bond clamp holds the seal, which is imbedded in a layer of silicone sealant, to the uptake. A similar seal holds the diaphragm to the rear wall, except that a split clamp is used. The rear seal provides uniformity in uptake gas temperature with less than two degrees Farenheit difference between the uptake mid section and primary nozzles. The uptake and seal are depicted in Figure 15.

The forward seal is within the plenum and consists of a bulkhead with removable aluminum plates that bolt to the mixing stack entrance. A double O-ring assembly assures proper sealing of the inlet outer circumference to the mixing stack.

2. Model Installation and Alignment

The model is supported independently of the seal plates by an adjustable support. Alignment is accomplished after mounting the model on the support and then installing the centering plates in each end of the mixing stack and in the open end of the uptake. Adjustment of the support will allow free movement of the alignment bar through the holes in the centering plates and therefore ensure proper alignment. Figure 25 shows the alignment bar installed in a typical model.

The straight primary nozzles are then installed and correct standoff distance is set. The distance from the nozzle exit plane to the entrance plane of the mixing stack is measured with a combination square, noting that the termination of the entrance radius = 0.5 inches. Normally less than 0.125 inches of adjustment is required to achieve a 0.5 standoff distance.

Eick [Ref. 10] observed a measurable longitudinal expansion and consequently the standoff distance was increased from 3.5610 inches to 3.6875 inches.

D. DATA ACQUISITION

To capitalize on technology a computer aided data acquisition system was utilized, replacing the manometers and LED thermocouple displays used previously. Original plans were to utilize a DEC computer and utilizing an interface card and software package, control HPIB compatible equipment. This procedure proved futile. Appendix A gives specific technicalities regarding the failed attempt.

A Hewlett-Packard computer replaced the DEC machine. The HP-85 was used to control a HP3497A scanner which was employed to acquire pressure and temperature data and transmit it back to the computer for processing and storage. A schematic of the data acquisition system is shown in Figure 8. The data acquisition program is listed in Appendix E.

Data reduction was accomplished on site after converting an existing program used by previous researchers from Fortran IV to HP Basic. Tabular output was also generated on site using a DEC LS34 plotter/printer via an RS 232 interface.

Detailed listings of equipment utilized and respective HP device codes are listed in Table II.

1. HP3497A Scanner

The HP3497A Scanner is a portable self contained data acquisition unit. The unit can either be remotely controlled by a computer or locally controlled via the front panel. The unit has the capability of acquiring data on 100 analogue, 80 digital, or 80 actuator channels. Physically located in the rear of the unit are five slots which, depending on the connection card utilized, determine the number of channels per slot available to the user. Table V depicts slot and channel assignment data.

The scanner was used to acquire all thermocouple and pressure data. Pressure data was acquired via a Scanivalve. The scanner, via software, also controlled the stepping, data transmission, and channel identification of the Scanivalve.

2. Pressure Measurement

Pressures were measured using a Scanivalve that allows sequential scanning or measurement of up to 48 pressure ports. Power supply to the pressure transducer is derived from a 5V DC power supply and the stepper motor is powered by a 24V DC supply. Transducer calibration was performed by simultaneously placing a pressure on a water manometer and the Scanivalve transducer and correlating the two readings. The correlation between transducer voltage and manometer reading is presented in Table III and Figure 37. A linear curve fit resulted in the following relation:

$$P[\mathrm{IN.}\ H_2O] = 1.56631 + 15189.94 * V \qquad \text{(eqn 4.2)}$$

where V is the pressure transducer voltage. Calibration was assured and checked at various intervals by manually connecting the water manometer to the entrance nozzle and correlating the pressure drop reading of the manometer with that of the pressure transducer.

3. Temperature Measurement

Two types of thermocouples were utilized. Combustion, uptake, and mixing stack wall temperatures were monitored by Type K thermocouples. Type T thermocouples were utilized to monitor inlet and ambient air, fuel, shroud, and diffuser ring temperatures. Reference 17 details specifications and reference voltages for the thermocouple types utilized.

Thermocouple voltage readings were reduced to actual temperature readings using National Bureau of Standards polynomial reduction coefficients. To effectively utilize computer memory a nested polynomial was used. The coefficients for each type of thermocouple are listed in Table IV and a typical reduction formula is shown below.

$$T[°C] = a_0 + x(a_1 + x(a_2 + x(a_3 + x(a_4)))) \quad (4^{th}\ \text{ORDER}) \qquad \text{(eqn 4.3)}$$

An eighth order polynomial was utilized to reduce Type K data and a seventh order polynomial for Type T data.

E. MODELS UTILIZED

Two eductor models were tested. Verification runs of the data acquisition system were conducted using Staples' Model A Modified [Ref. 12] as the pumping characteristics of this model was known, hence providing a validity check for the computer system. Characteristic model dimensions are shown in Figure 6. The nominal diameter of the mixing stack is 7.122 inches, is the same dimension used in previous research, and is 0.6087 scale of the cold flow models. The second model was similar to the first except that the diffuser ring geometry was altered to reduce local hot spots identified by previous research. Figure 6 depicts nominal dimensions. Table VI shows a comparison between the characteristics of the two models.

The primary nozzle plate, common to both eductors consists of four angled and tilted nozzles. Nozzle tilt is 15 degrees from vertical and rotated inward 20 degrees from the tangential direction. Figure 32 details nozzle geometry and Figure 29 depicts a typical model installation.

Model A Mod is discussed in reference 12 and detailed dimensions are shown in Figure 3. Figure 4 depicts the dimensions of the reconfigured model. The major modification was to the ring assembly. Although six rings were employed, as with Staples' model, the characteristics of each specific ring were altered to, as mentioned earlier, reduce local hot spots. Figure 34 details individual ring specifications. Thermocouples were installed along the length of the shroud to serve as a comparison to readings obtained from a hand held Omega Engineering 871 Digital thermocouple.

V. EXPERIMENTAL RESULTS

A. MODEL A MODIFIED RESULTS

Figures 38 and 39, supported by Tables IX and X, depict the pumping performance of Staples' Model A Modified as collected by the HP 85 data acquisition system. These two temperatures bracket those tested by Staples and correspondingly, also bracket the pumping coefficient data collected by Staples. Based on these results the validity of the data acquisition system was confirmed and modification to the diffuser rings begun.

B. MODEL B RESULTS

1. Pumping Ability and Mach Number

Figures 40 through 50 and Tables XI through XXIX represent the data, both raw and processed, obtained with this model. Figure 52 represents a summary of pumping coefficient verses Mach number at the two uptake temperatures studied.

It should be noted that two data tables are presented for each Mach number. The research showed that the pressure drop across the entrance nozzles (DELPN) varied significantly during the runs. This can be found by examining the first table for each Mach number. This is due to the method of data acquisition. The scanivalve allows a one time look at a specific channel, hence not allowing for transients inherent to this type of test facility. In an effort to reduce the data scatter the pressure readings were averaged over the eleven pumping characteristic runs. The second table at each Mach number represents this data. The value of the pumping coefficient was found not to vary with the method of data reduction and therefore only the actual data taken is graphically represented.

At an uptake temperature of 175^{O}F a slight increase in pumping coefficient occurs with decreasing Mach number. This relation is extremely vivid at the higher uptake temperature of 950^{O}F. A 15% rise in pumping coefficient was realized between M=.06 and M=.024. Closer examination of the data reveals the same relative increase in secondary to primary mass flow rates, accounting for this increase.

At M=.06 the pumping coefficient is greater than that reported by Staples for Model A Mod with no crossflow [Ref. 12].

2. Exit Plane Temperature Profile

Graphical representation of this data is presented in Figures 53 through 57. Table XXXI contains the tabulated data.

The data collected at a Mach number of .06 is lower than that collected by Staples, as was expected due to the increase in pumping coefficient. A maximum exit plane temperature of 579^{O}F was noticed whereas Staples noticed a maximum of 586^{O}F.

No significant degradation or increase was noticed as the Mach was varied. A slight increase in the profile was noticed at the outer edges of the exit plane, resulting in a slight increase in outer diffuser ring temperature. Good symmetry was noticed in the data at all Mach numbers tested.

3. Mixing Stack Temperatures

Table XXXII contains the data presented graphically in Figures 58 through 62 regarding mixing stack temperatures.

Originally twelve Type K thermocouples were used to determine the film cooling effectiveness of the slotted mixing stack. Figure 3 depicts the location of these thermocouples. One thermocouple, number 7, ceased to operate during cold flow testing and due to testing requirements was not replaced.

At M=.06 the maximum wall temperature noted is 346°F which is lower than that reported by Staples (357°F) but higher than that reported by Kavalis (320°F). Kavalis [Ref. 11] reported that the flow interior to the mixing stack was not uniform due to the nozzle induced swirl. This is again discussed by Staples [Ref. 12] and also supported in this research. Relatively large temperature differentials exist between adjacent thermocouples as a result of this non-uniformity.

Regarding Mach number, a slight temperature variance was noticed as the Mach number changed, especially at M=.024. This variance was not significant, however.

4. <u>External temperatures</u>

Figures 63 through 67 and Table XXXIII depict the data collected externally to the model. External measurement locations are presented in Figure 33. Type T thermocouples were utilized to monitor diffuser ring temperatures as well as selected locations along the shroud.

Staples [Ref. 12] reported a transient nature to the data obtained using the portable Type K Omega Thermocouple probe. This phenomenon was not noticed during this research and excellent correlation ($\pm$ 0.1°F) between this portable thermocouple and those permanently installed was achieved. Consequently, the probe data at installed thermocouple locations is not presented. The probe was essential in examining locations exterior to the shroud and diffuser rings not covered by installed thermocouples. Fifty to sixty locations were checked during each run, looking for "hot spots," especially in the vicinity of the mixing stack termination. No temperatures greater than those listed in Table XXXIII were located.

Diffuser ring temperatures at M=.06 are significantly lower than those reported by Staples [Ref. 12]. Although ring temperatures increase slightly with decreasing Mach number, they remain lower than those reported by Staples. The increase in pumping ability accounts for this fact.

A temperature "spike" at X/D = 1.068 was reported by Staples. This location is at the termination of the mixing stack. Ring was extended from L/D = .1 to L/D = .3 to shroud this location. Omega probe readings at this location showed significant temperature reduction at all Mach numbers.

Temperatures along the shroud also were lower than those reported earlier, except at X/D = .125, where they were higher.

Mach number has slight effect on these temperatures, however, the maximum external temperature remained lower than that reported by Staples.

5. Mixing Stack Pressures

Figures 68 through 72 and Table XXXIV contain the mixing stack pressure data.

All mixing stack pressures were effected by Mach number variance, increasing with decreasing Mach number. This would account for the increase in wall temperatures noticed.

VI. CONCLUSIONS

The implementation of a computer aided data acquisition system and the study of Mach number effects on exhaust gas stack eductors have been the salient features of this research. Based on the data collected the following conclusions are postulated:

1) The data acquisition system significantly enhances data collection and reduction, however, certain precautions need to be taken to prevent data scatter.

2) The shroud and diffuser design studied is more effective and efficient than previous designs.

3) Mach number decreases improve overall eductor performance.

4) No increase in external temperature occurs with decreased Mach number.

5) Exit plane temperature profile is not significantly affected by Mach number.

VII. RECOMMENDATIONS

Prior to testing future models or designs for fleet use the following is recommended:

1) Modify the fuel system to allow greater control at higher Mach numbers. This should include replacement of the high pressure pump and motor and replacement or overhaul of the fuel control valve. A variable speed pump and motor combination is recommended to facilitate more accurate fuel pressure control and avoid the decrease in pump efficiency from heating.

2) Install a flow metering device in the fuel supply system to assist in data acquisition.

3) Monitor entrance nozzle pressure drop at 4 or 5 scanivalve channels via a manifold arrangement to decrease data scatter at low flow rates.

4) Replace the inlet air valve with a motor controlled valve similar to the cooling air bypass and burner air valves to allow positive control of the inlet air at the control station. Control is essential at low flow rates due to the increase in burner temperatures.

5) Modify the fuel fill system to enhance refueling and avoid spillage.

6) Install an additional LED display to allow simultaneous monitoring of burner and uptake temperatures.

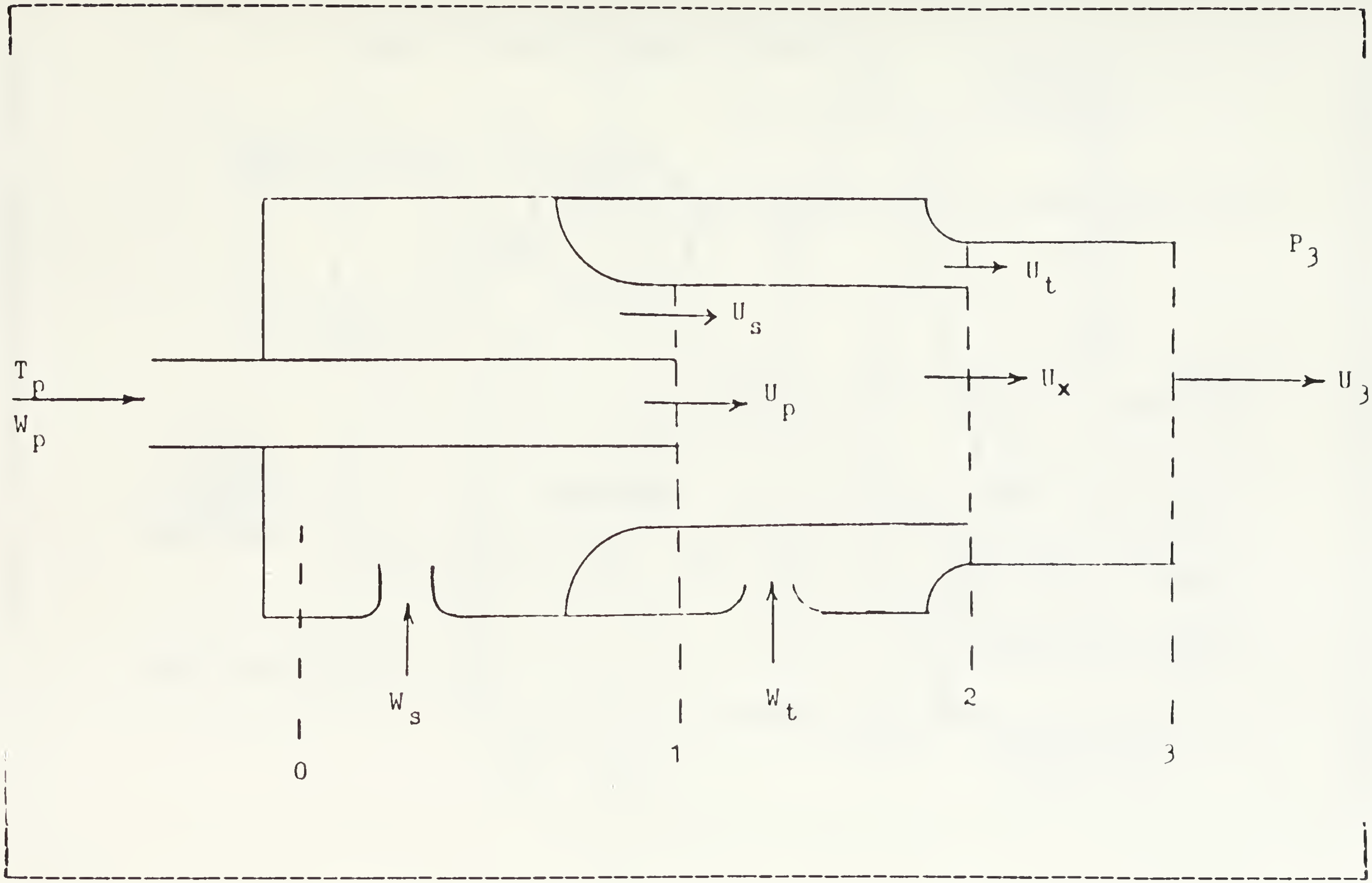


Figure 1. Simple Nozzle Eductor System.

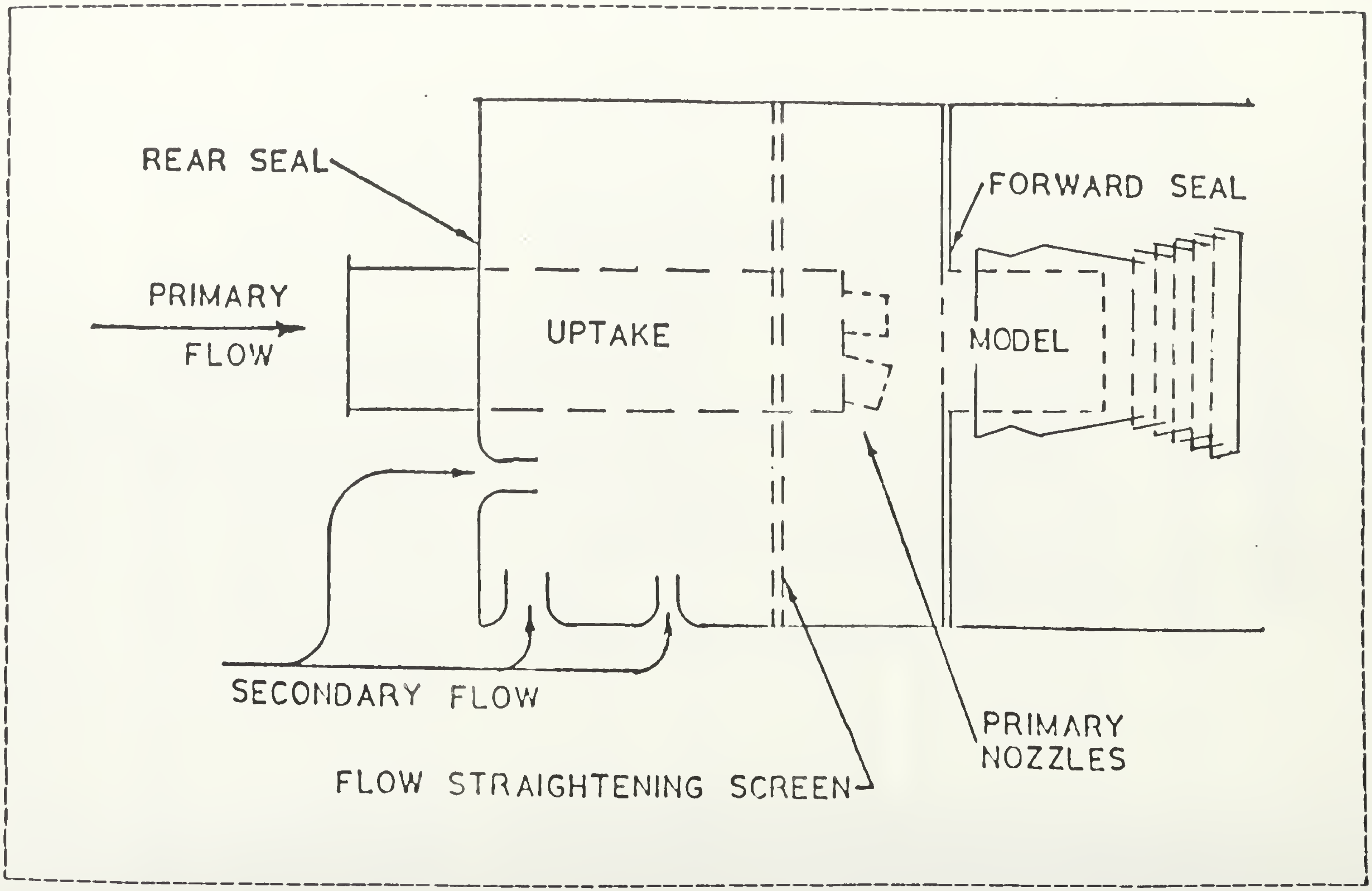


Figure 2. Plan of Uptake, Model, and Measurement Plenum.

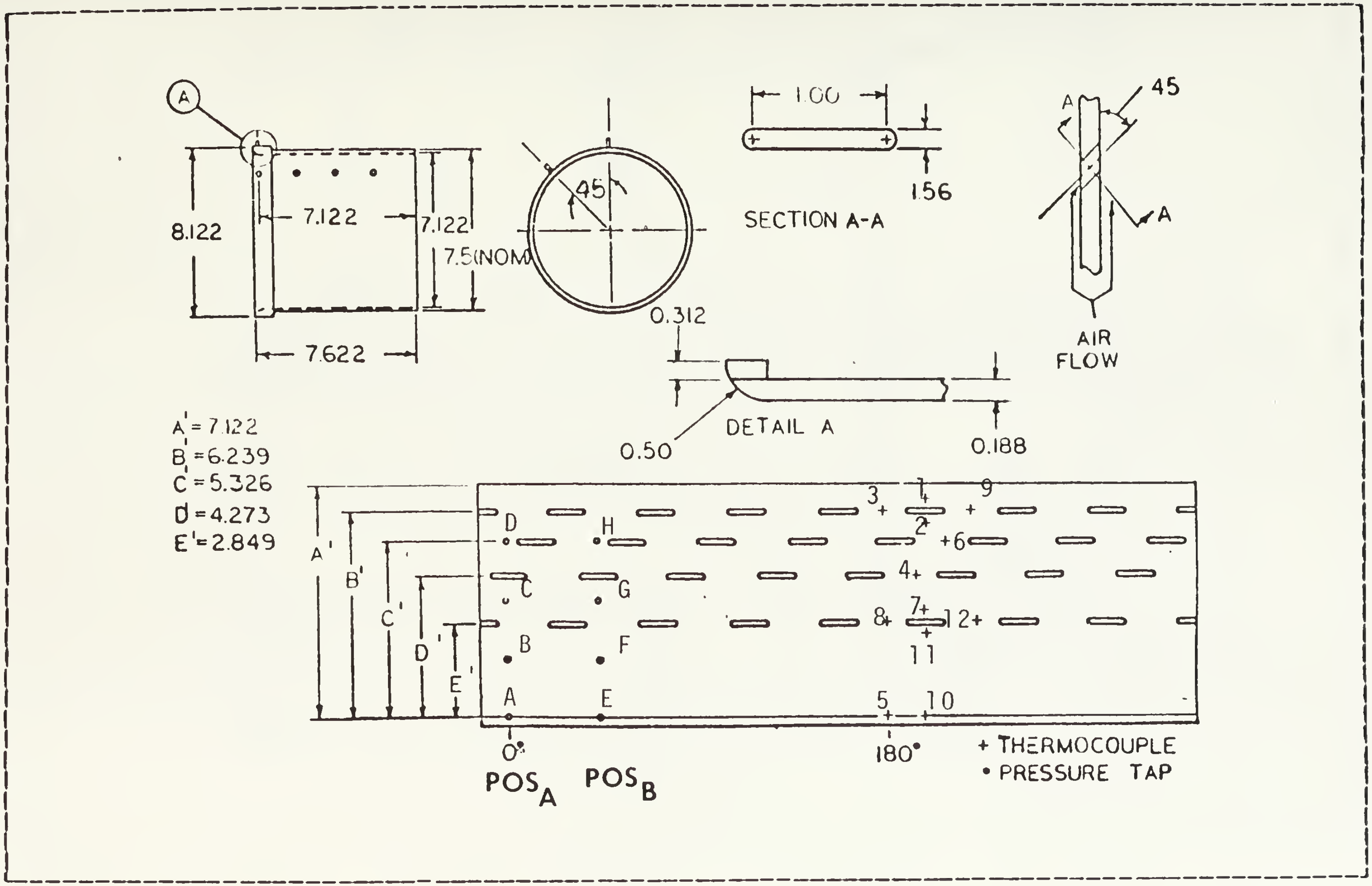


Figure 3. Dimensional Diagram of Slotted Mixing Stack.

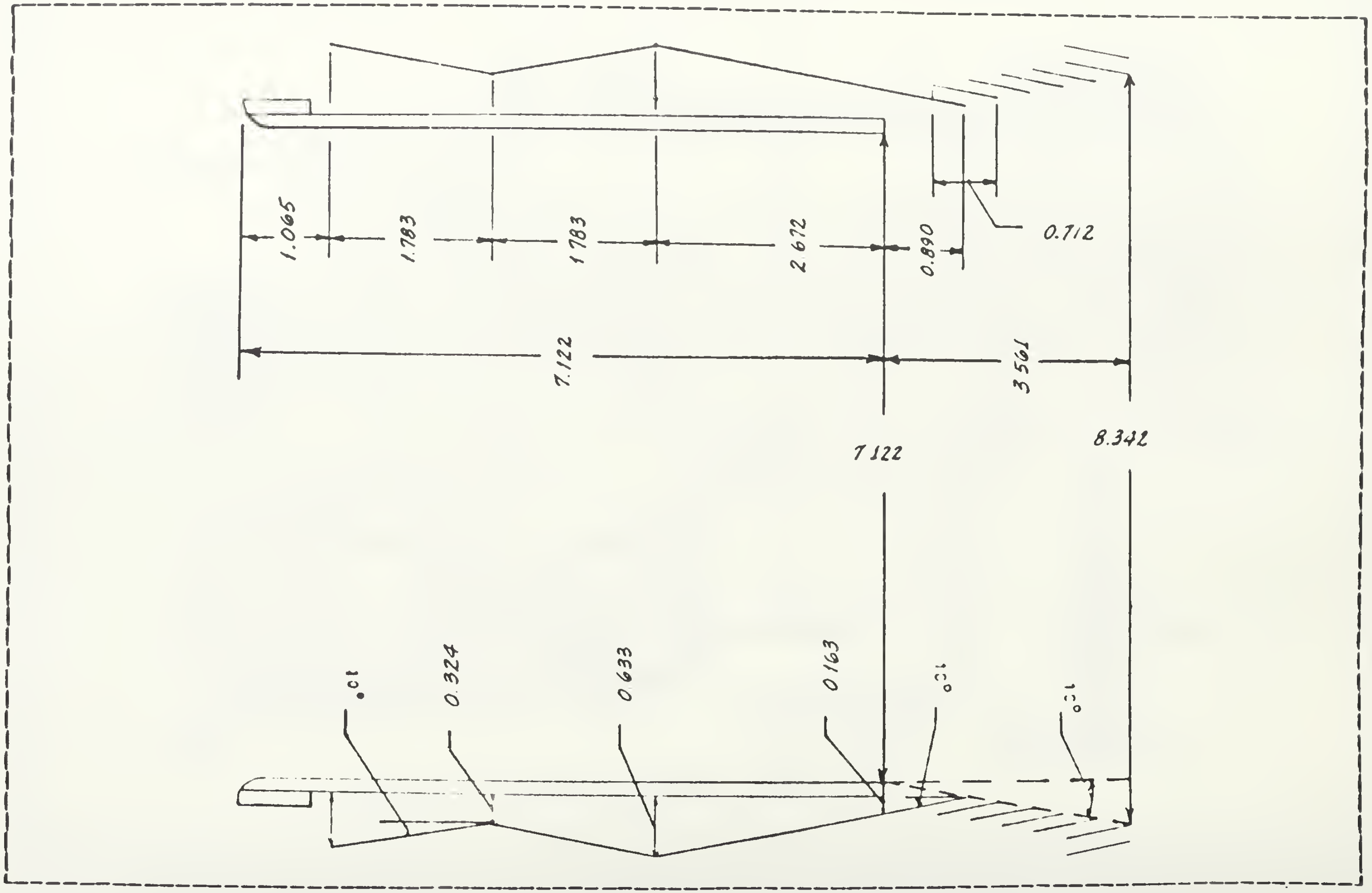


Figure 4. Schematic of Model A Modified - Shroud and Diffuser Rings.

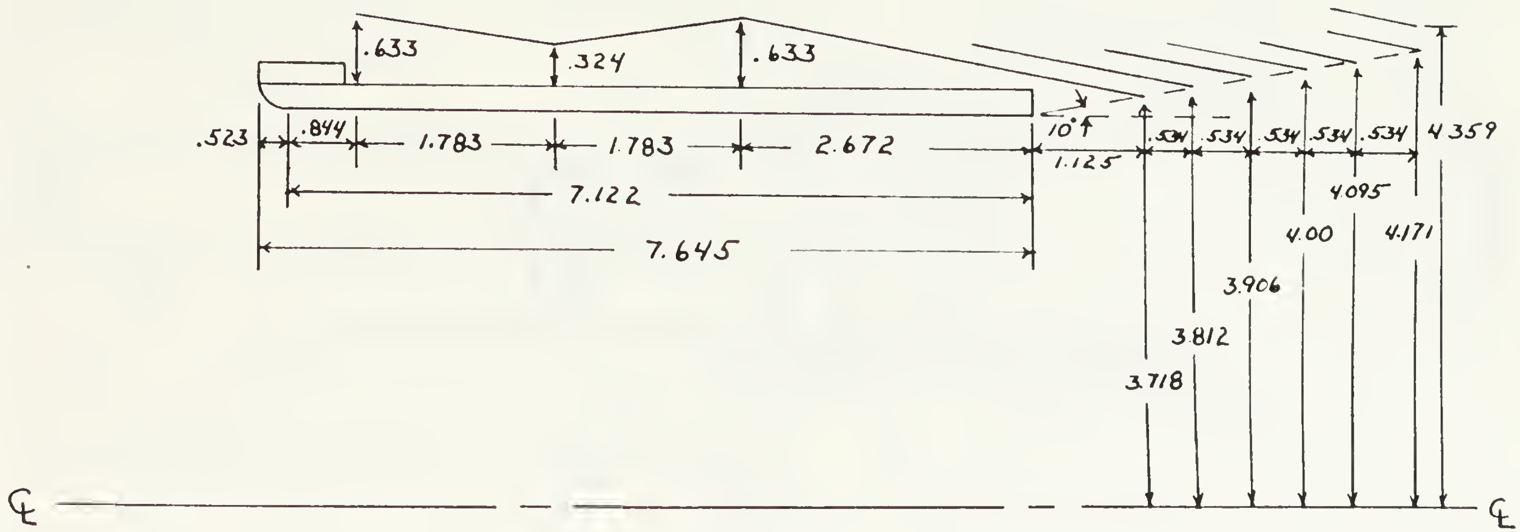


Figure 5. Schematic of Model B - Shroud and Diffuser Rings

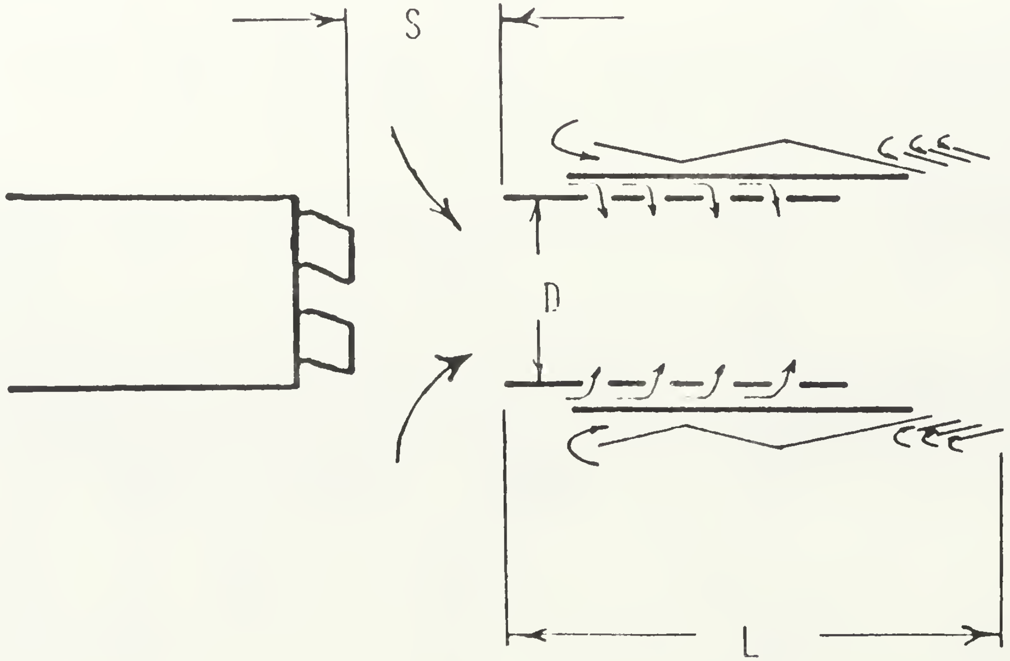


Figure 6. Characteristic Eductor Dimensions.

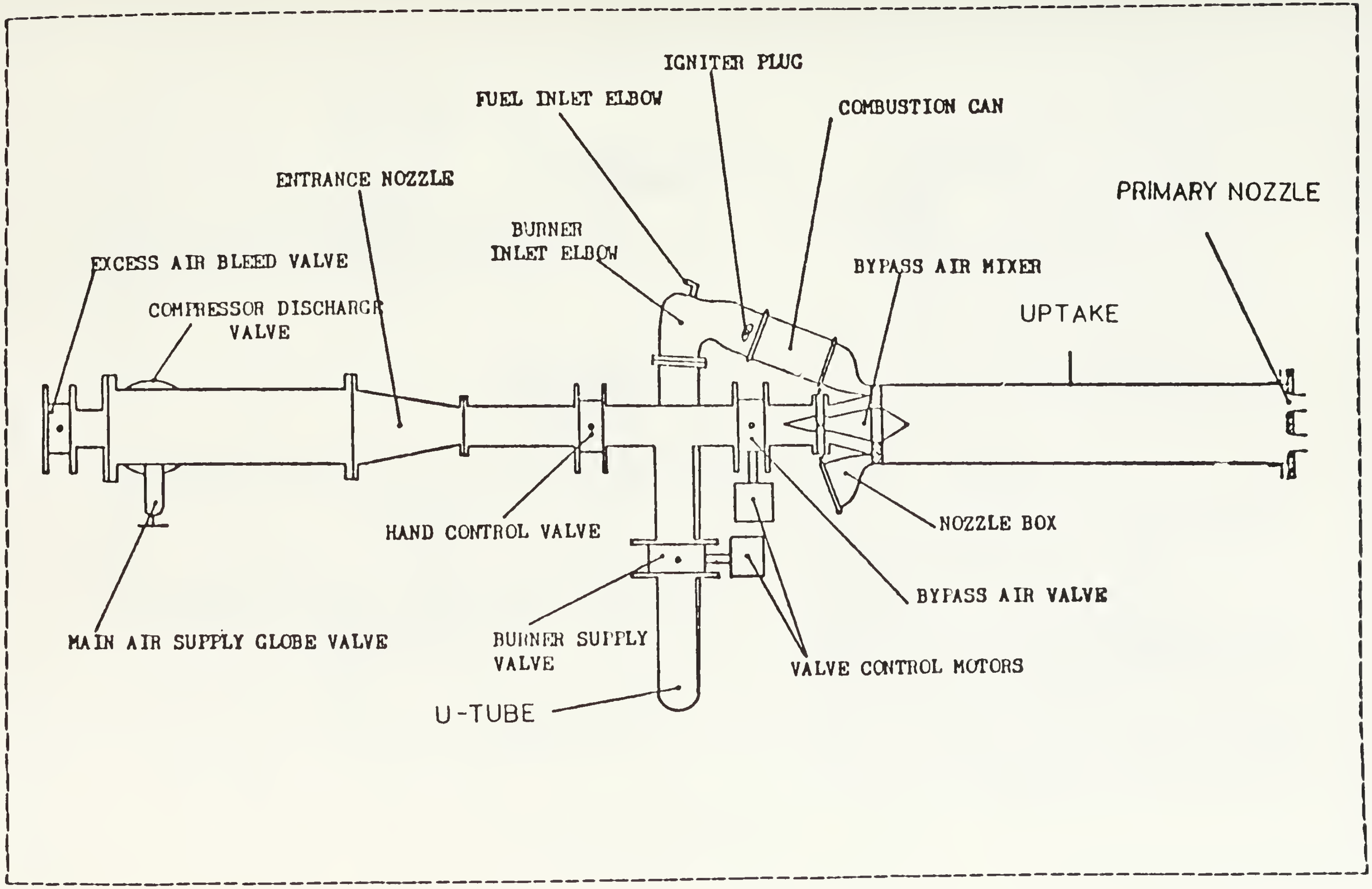


Figure 7. Gas Generator Arrangement.

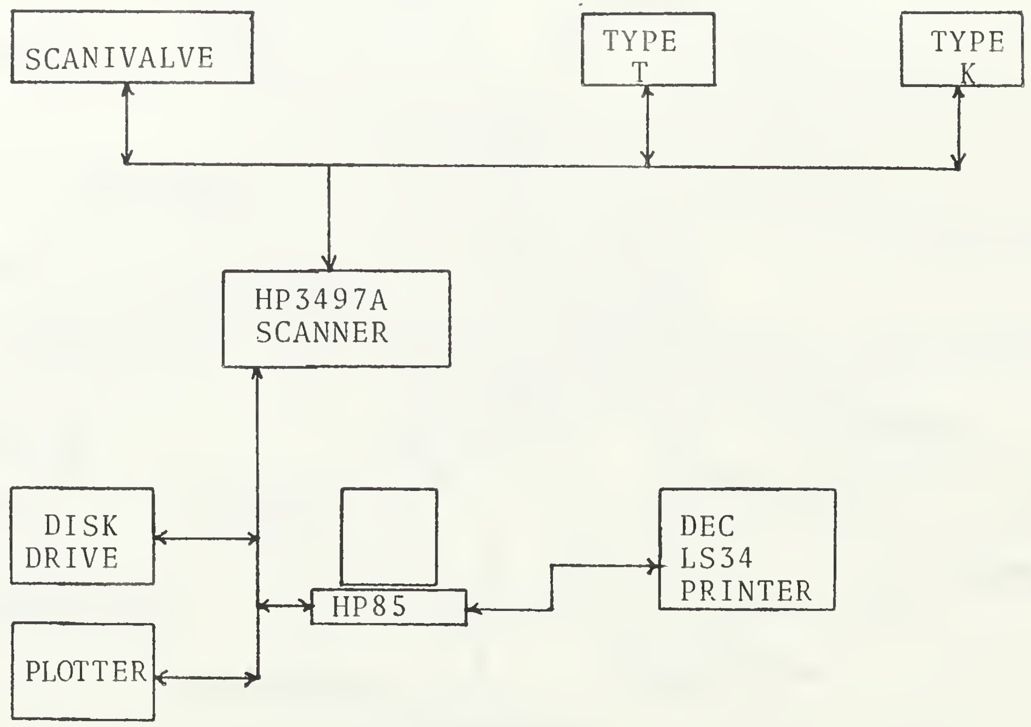


Figure 8. Schematic Diagram of Data Acquisition System

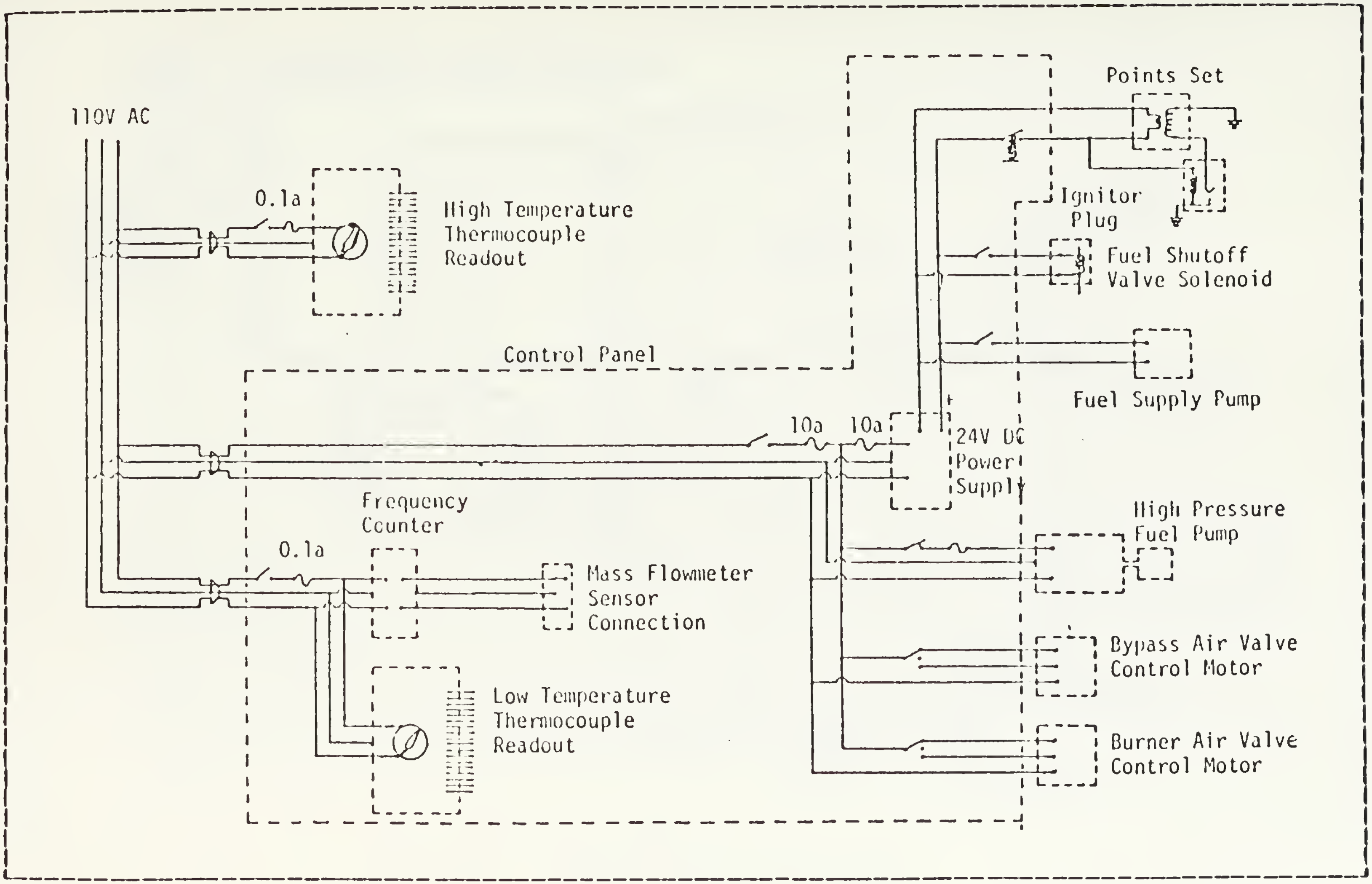


Figure 9. Gas Generator Electrical System.

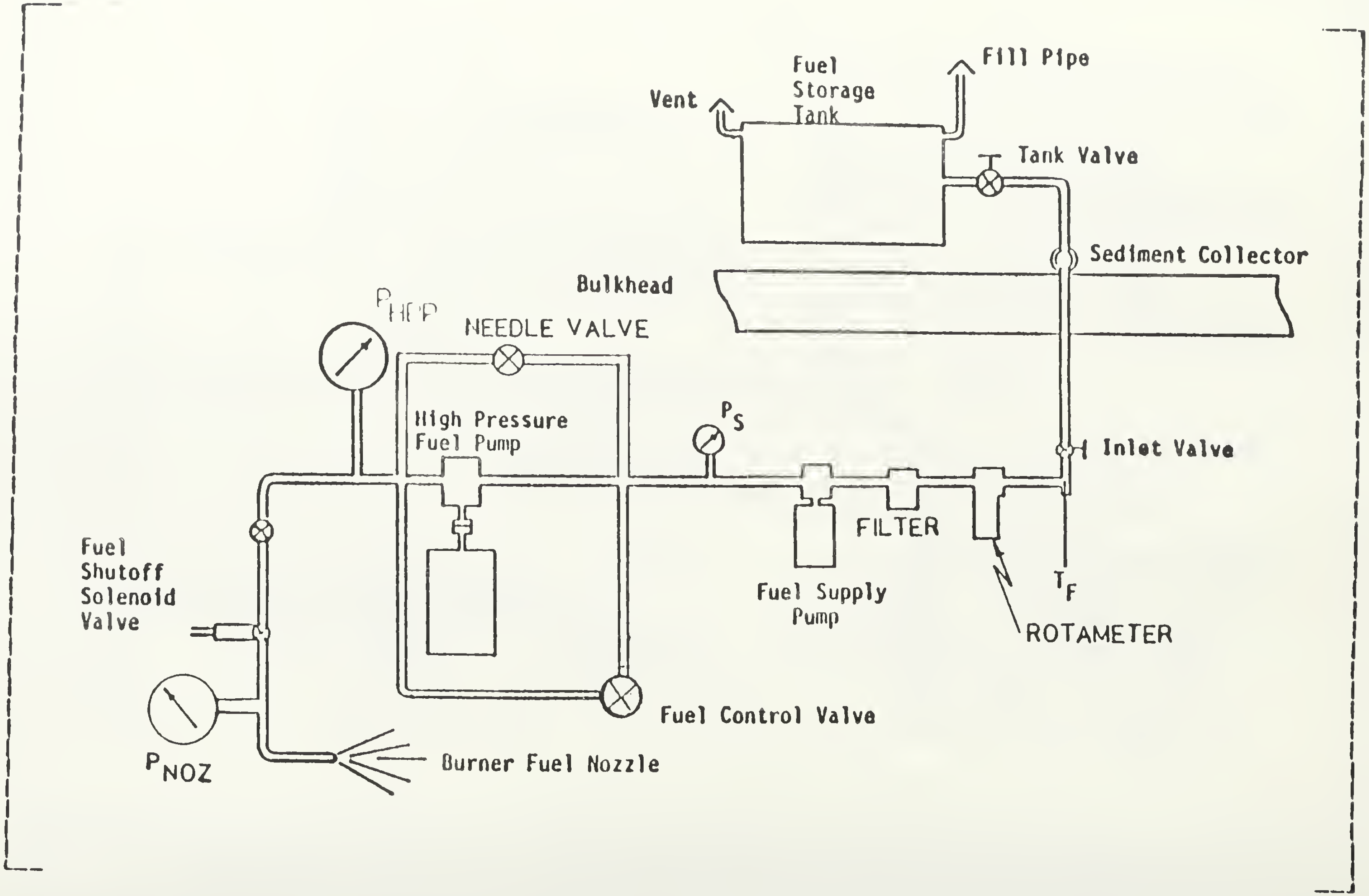


Figure 10. Gas Generator Fuel System.

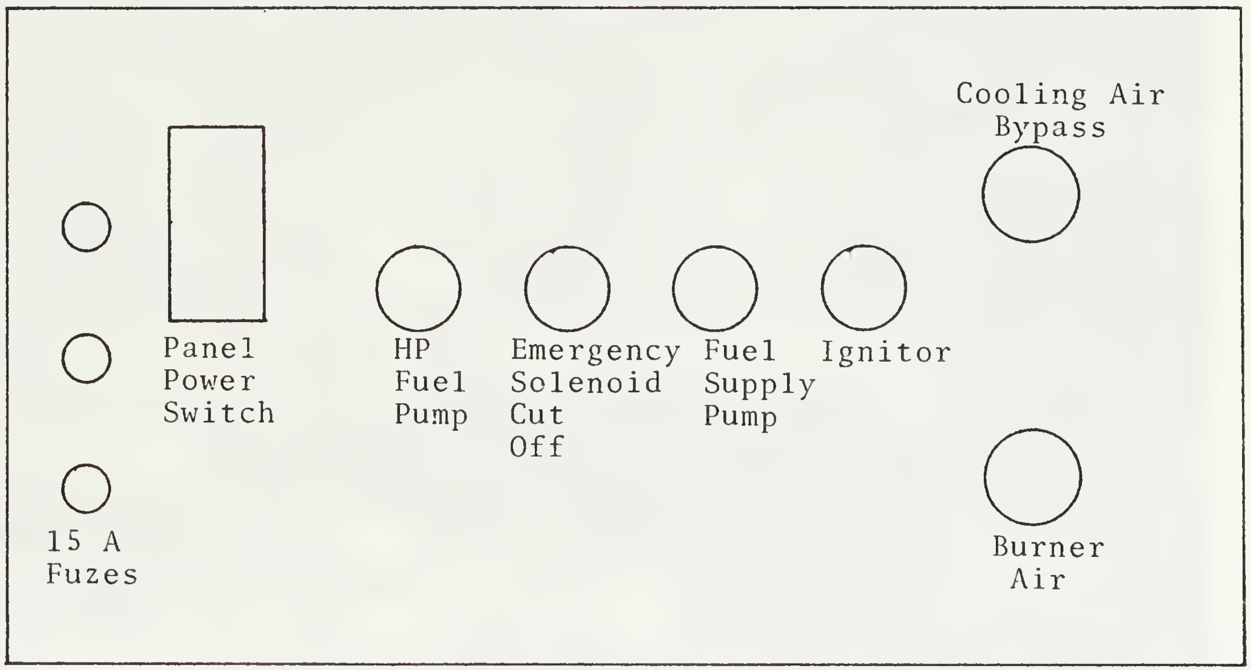


Figure 11. Control Panel Diagram

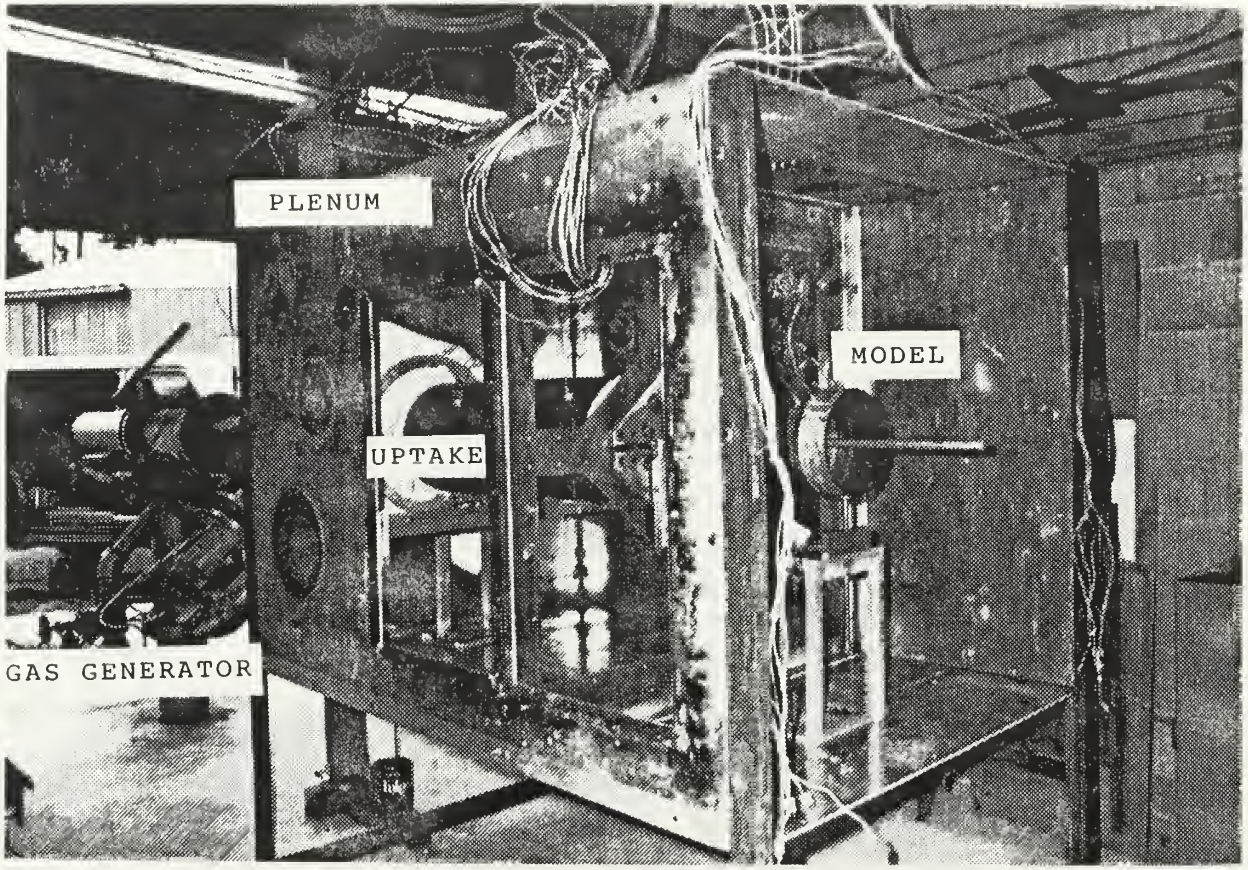


Figure 12. Hot Flow Test Facility.

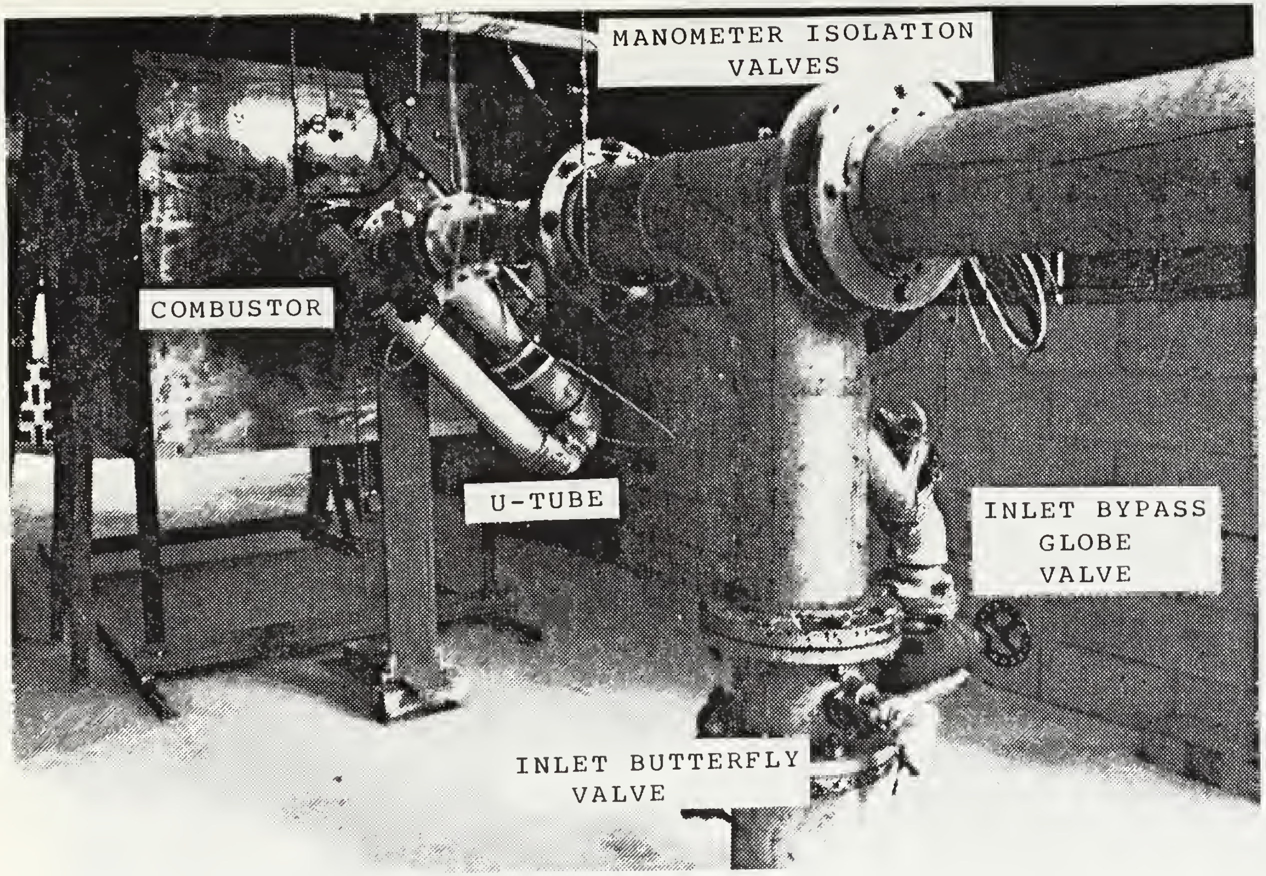


Figure 13. Air Supply Standpipe and Valving.

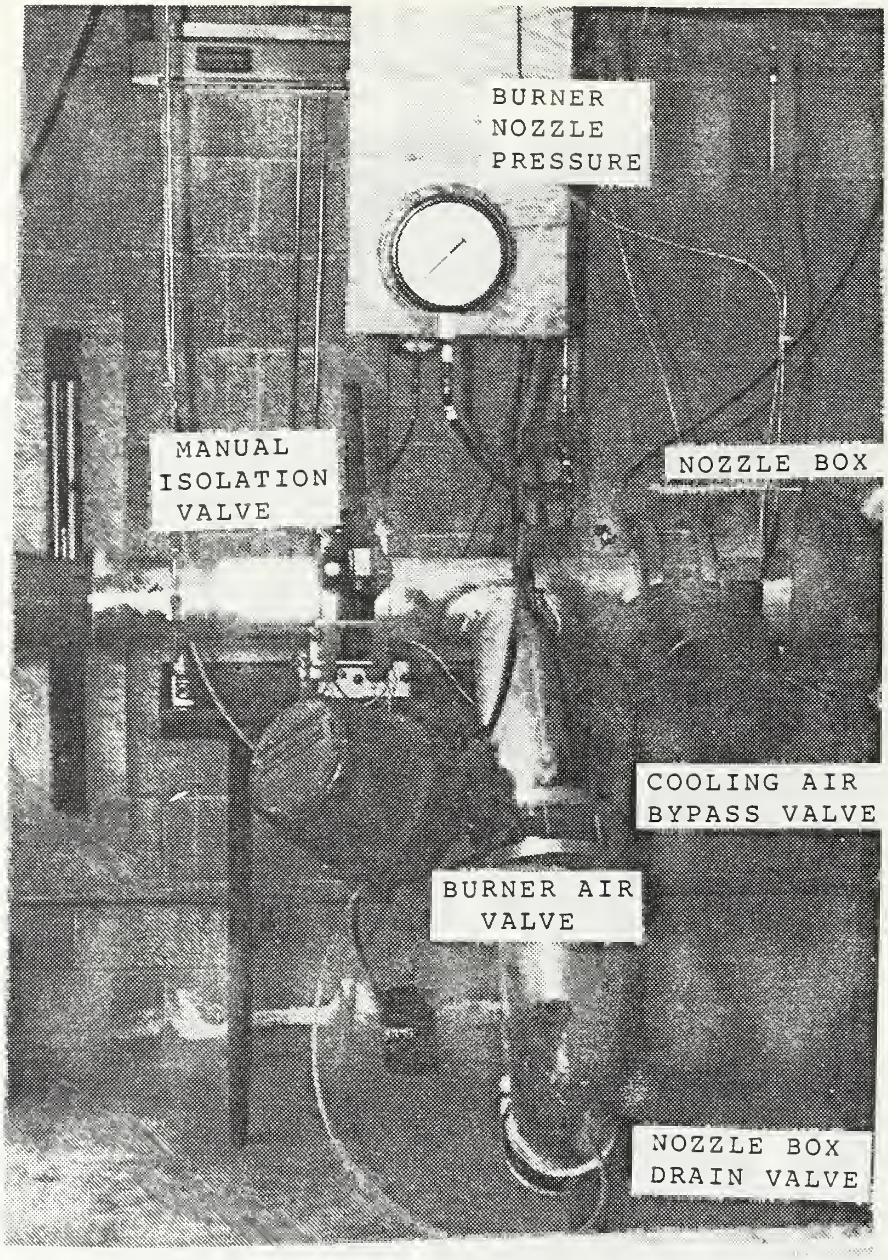


Figure 14. Combustor Air Piping.

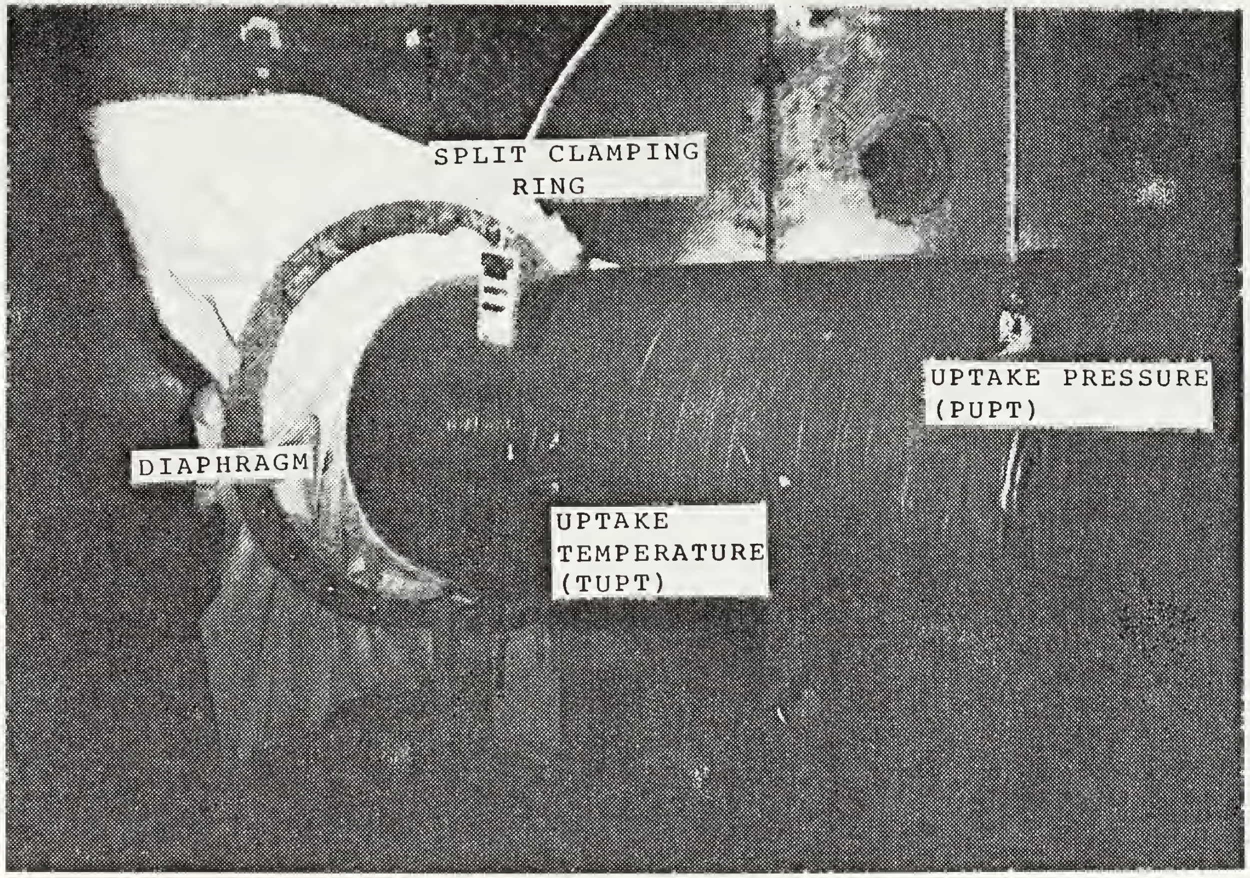


Figure 15. Uptake Section.

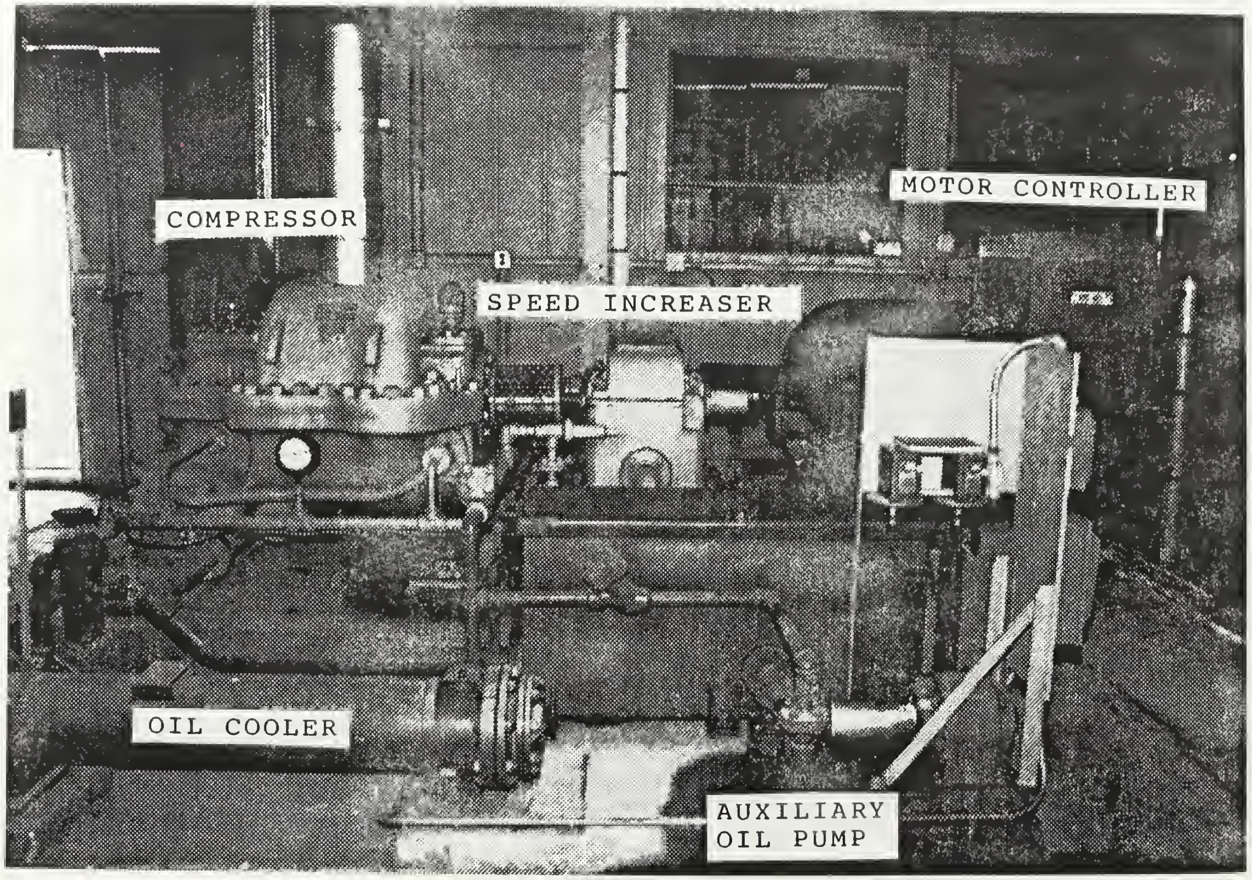


Figure 16. Carrier Air Compressor.

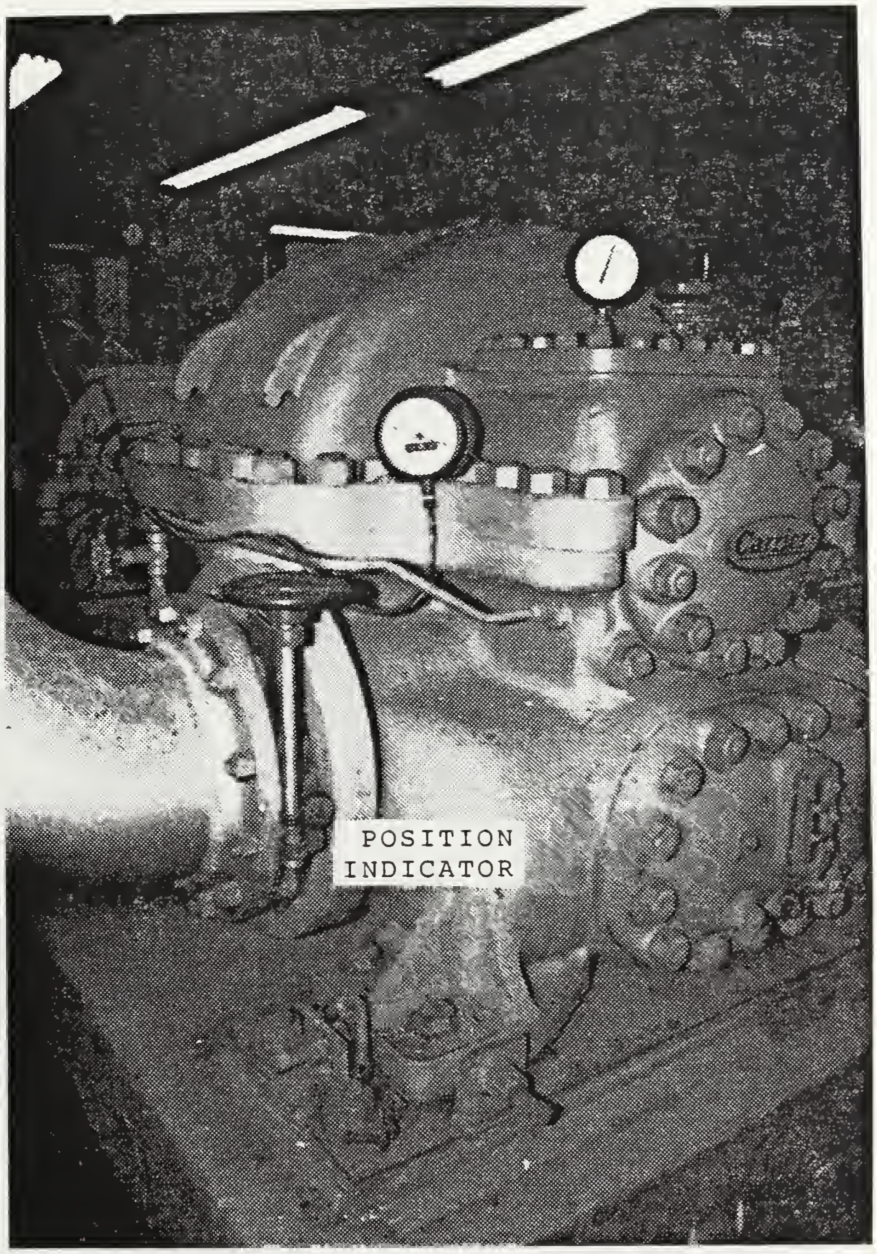


Figure 17. Air Compressor Suction Valve.

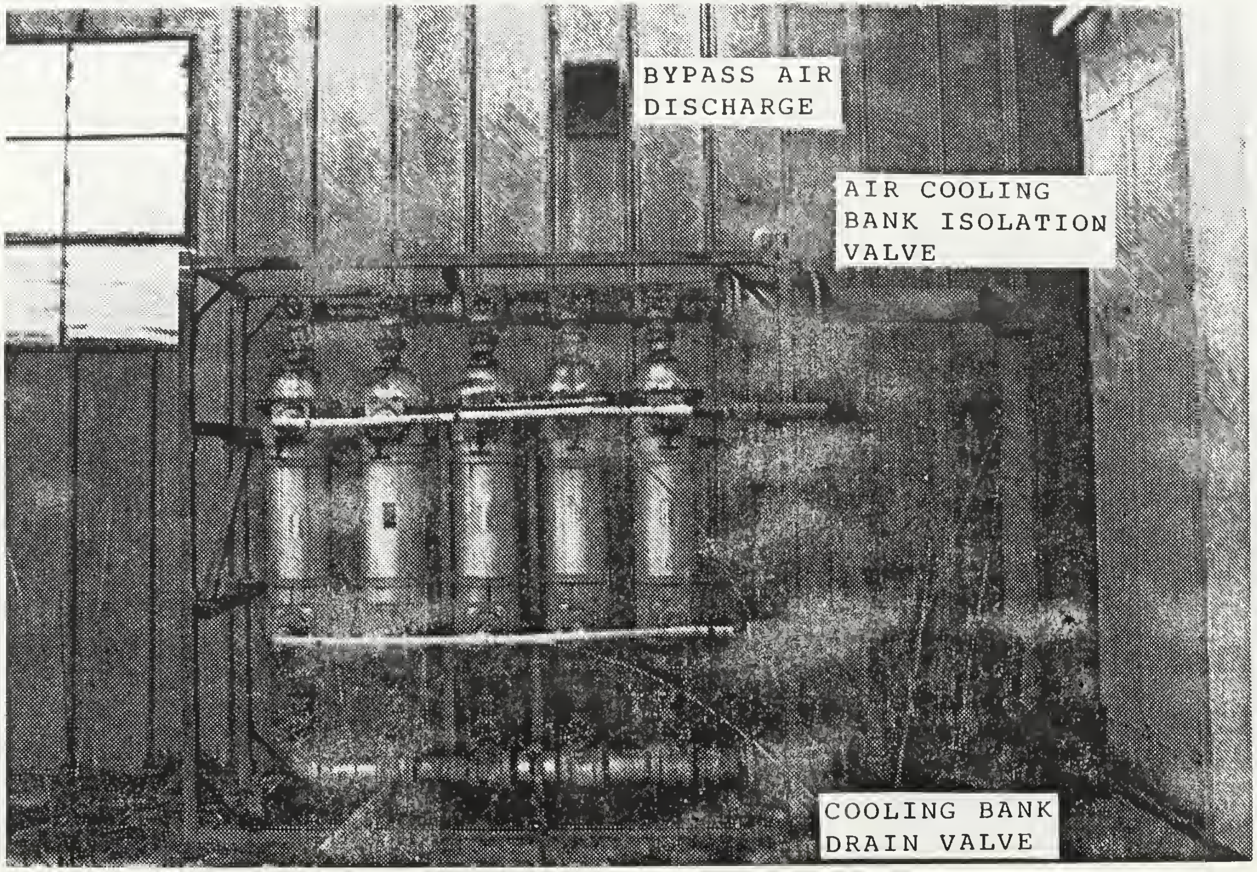


Figure 18. Air Cooling Bank and Bypass Discharge.

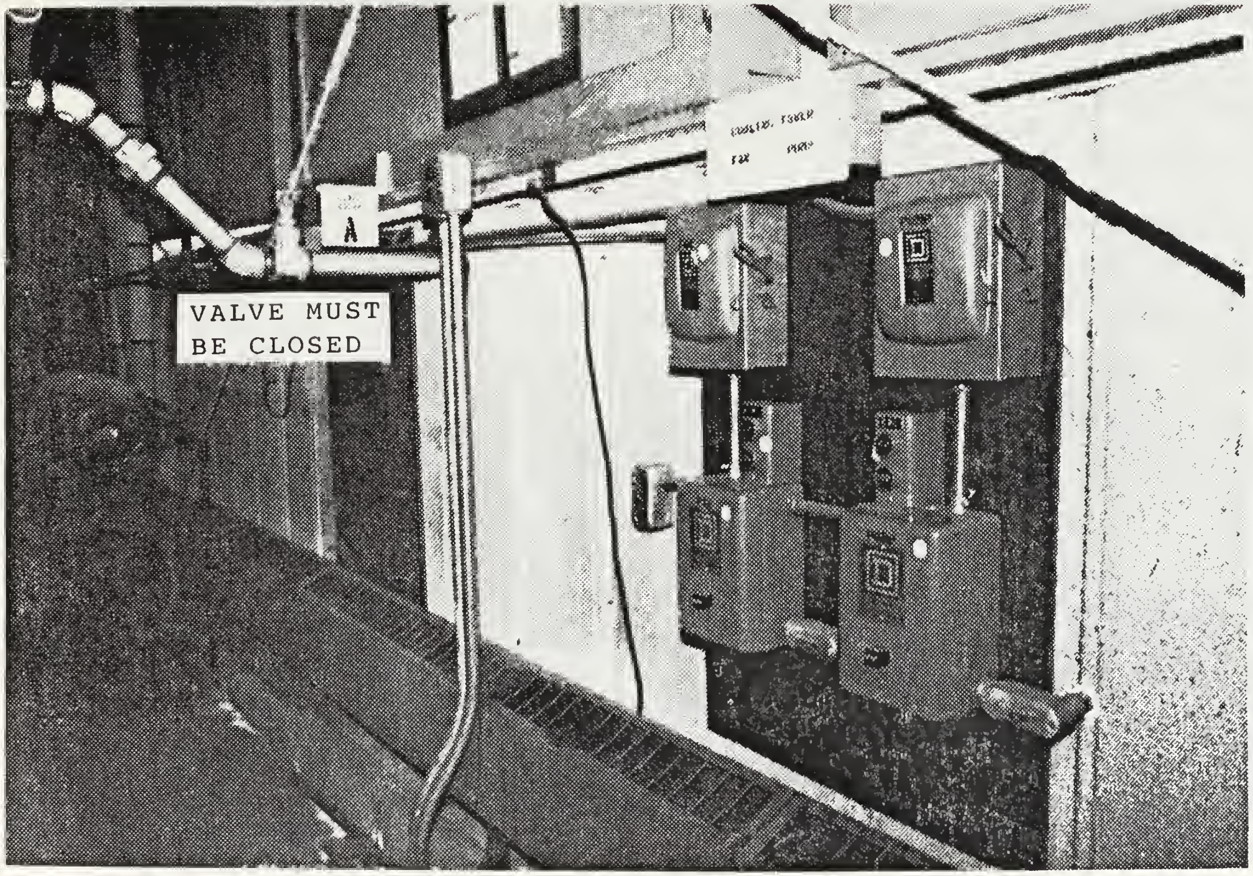


Figure 19. Cooling Water Pump and Tower Fan Controllers.

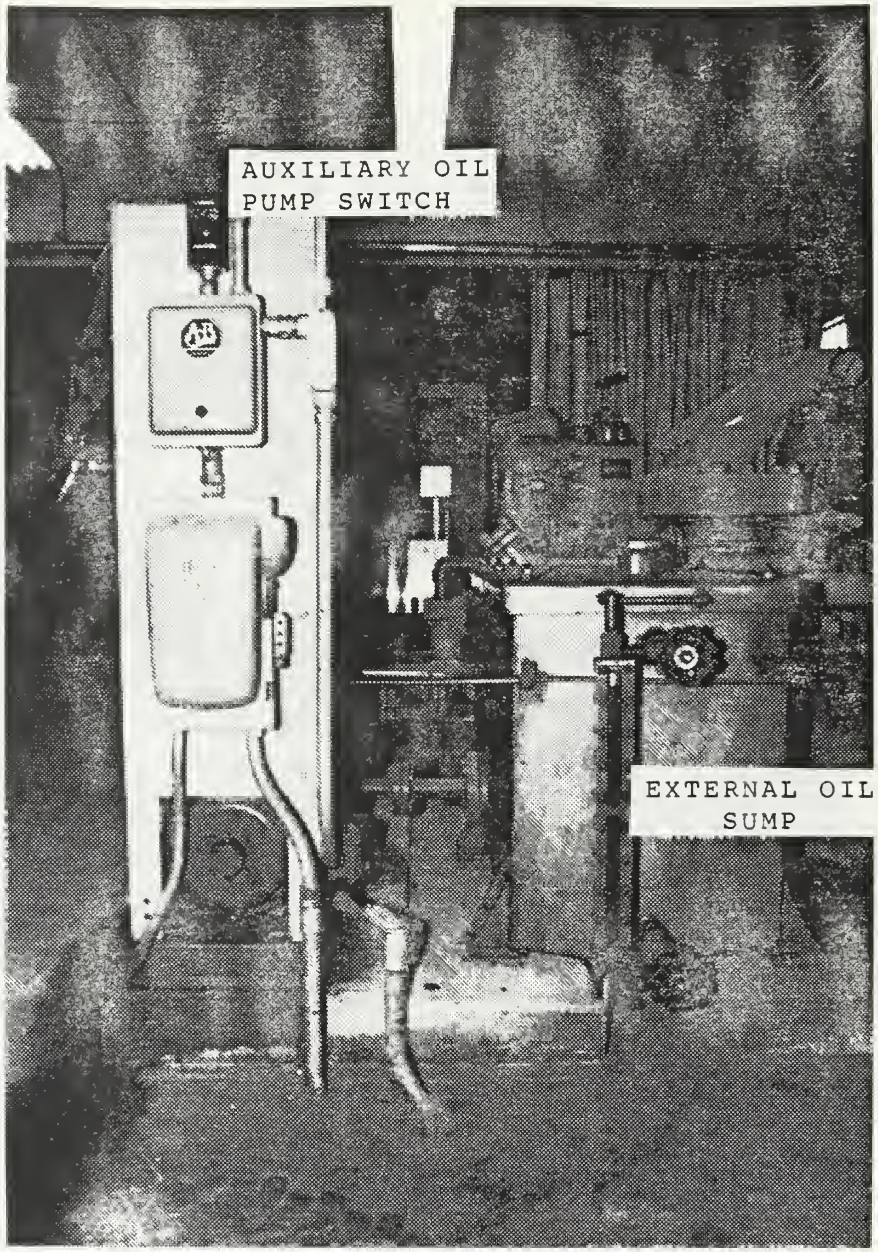


Figure 20. Auxiliary Oil Pump Control.

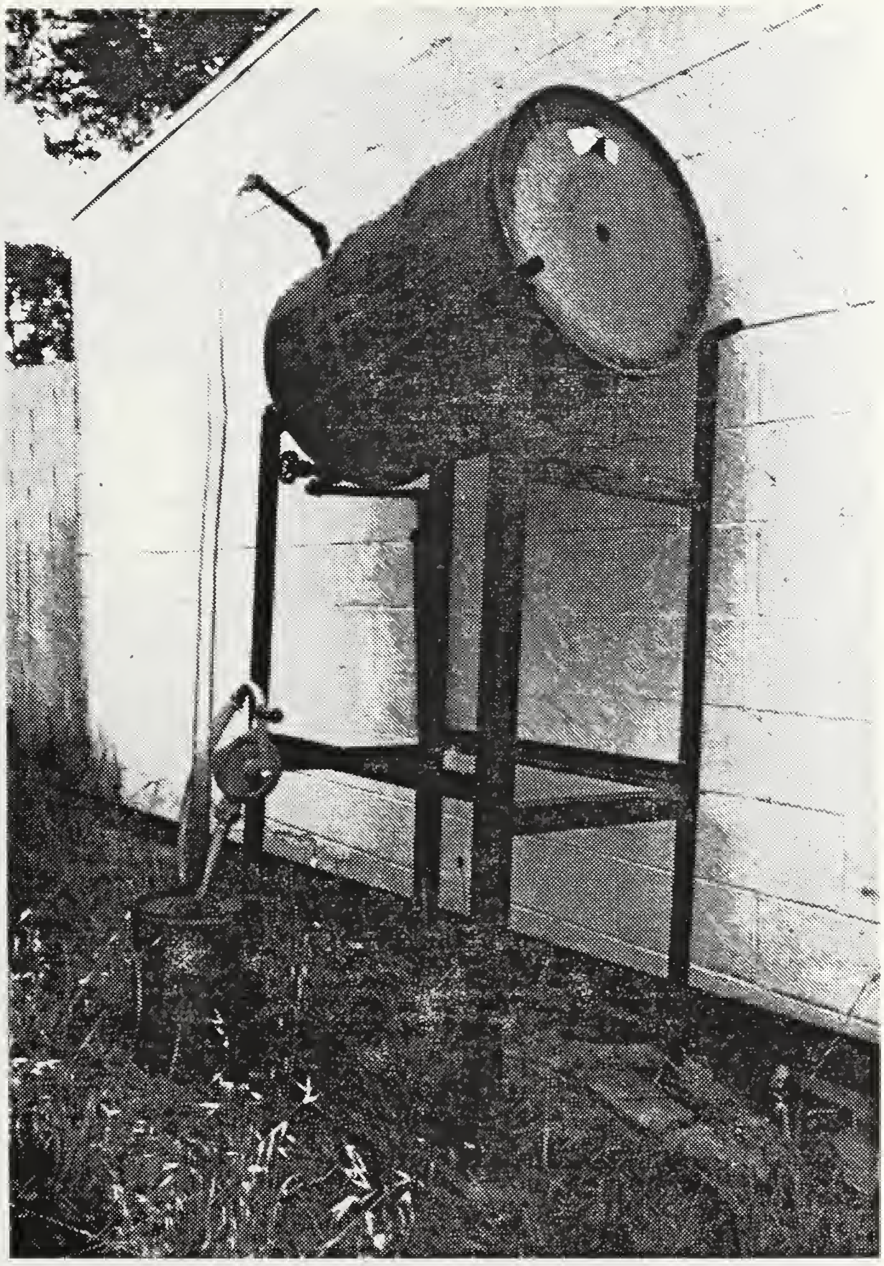


Figure 21. Fuel Service Tank

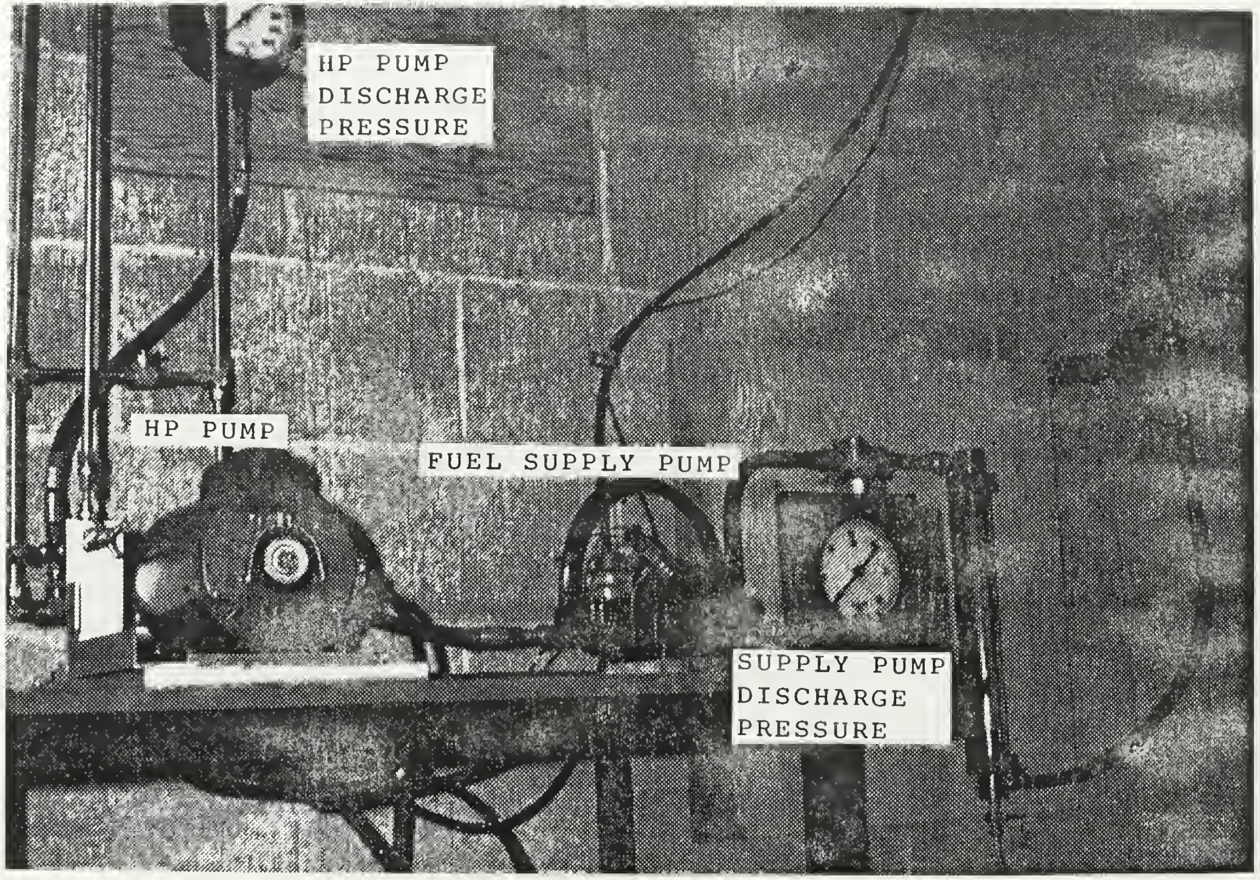


Figure 22. Fuel Pump Installation.

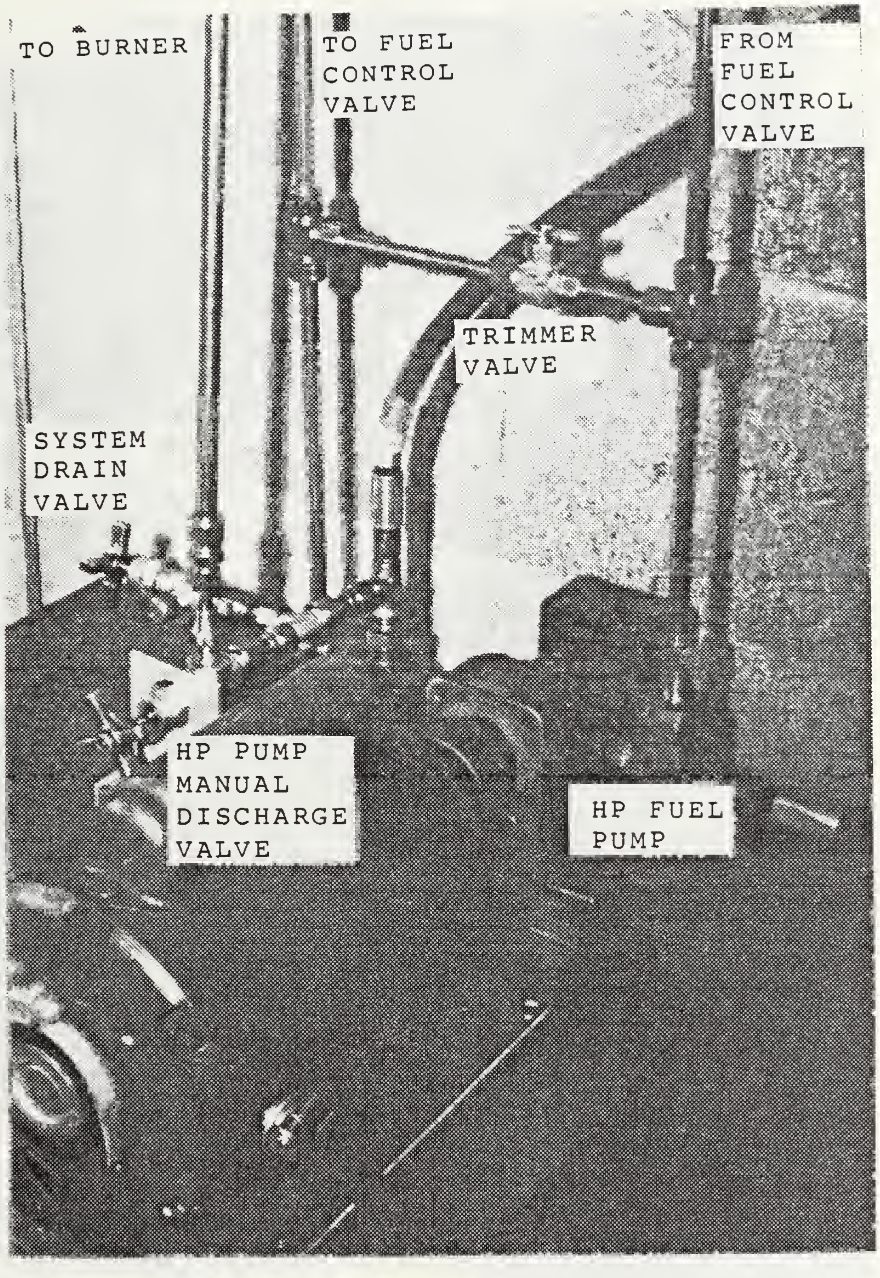


Figure 23. H. P. Fuel Piping and Valves.

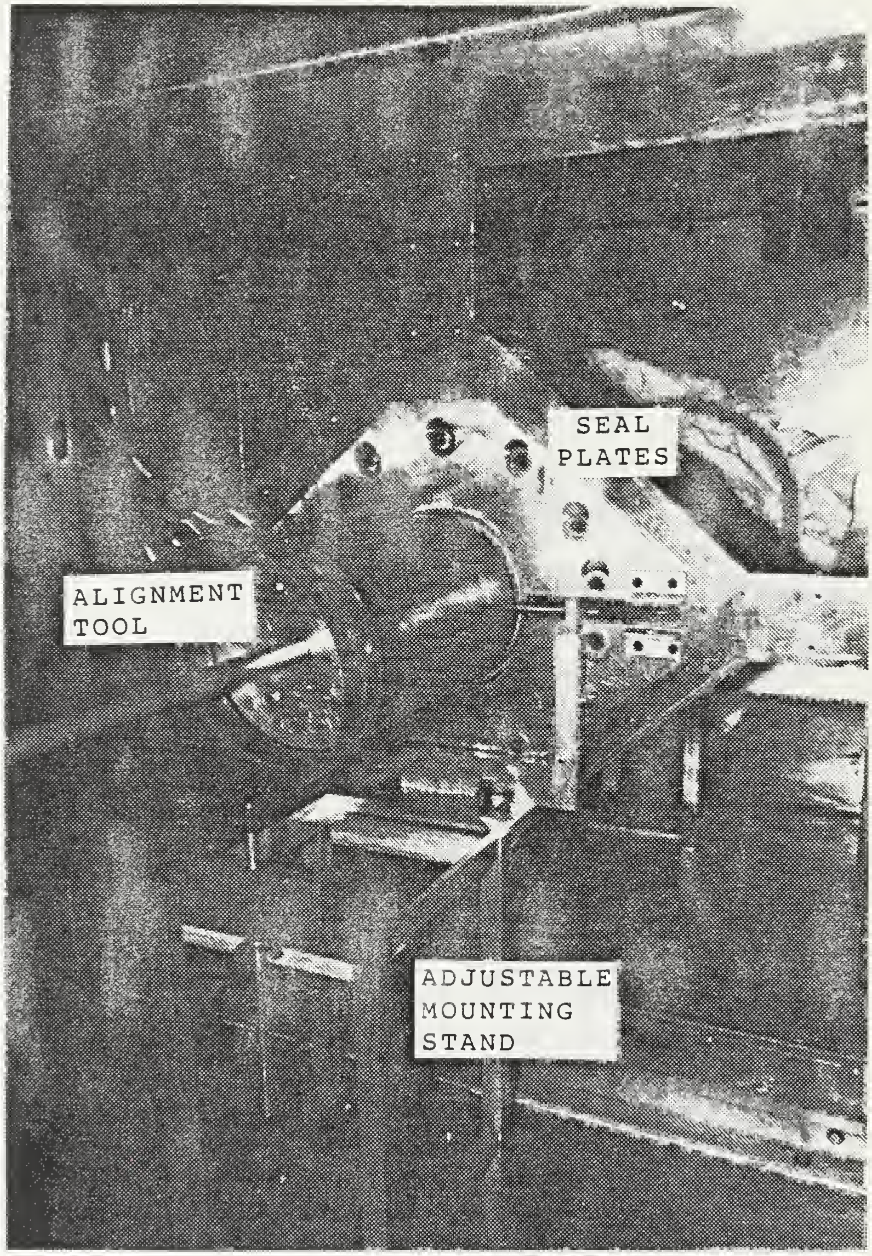


Figure 24. Model Installation.

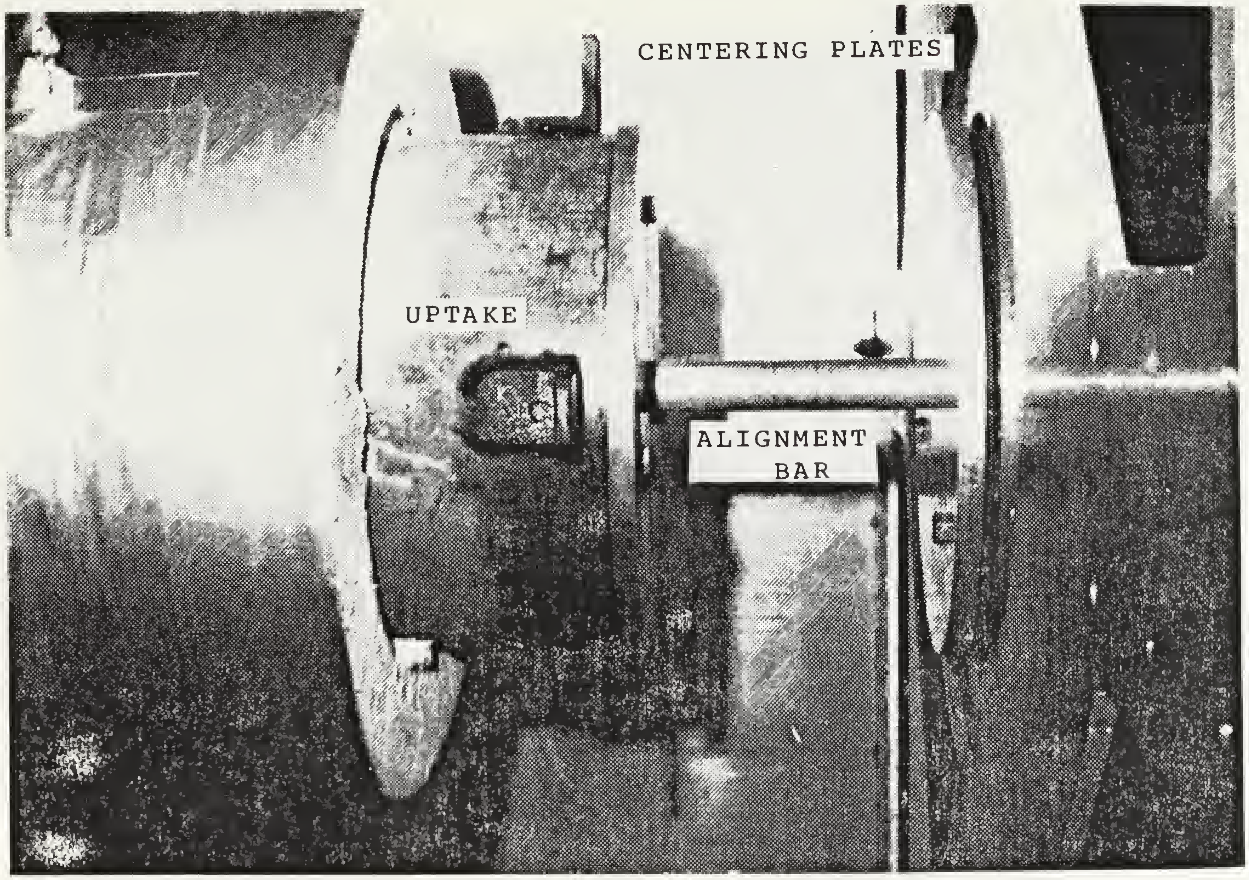


Figure 25. Model Alignment.

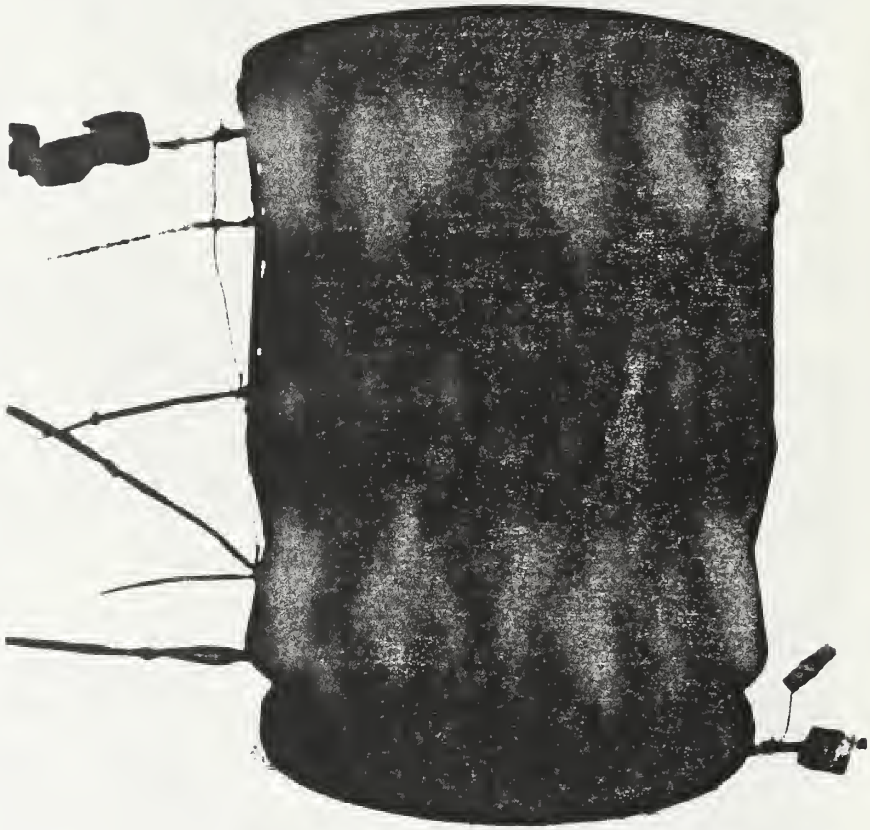


Figure 26. Model B

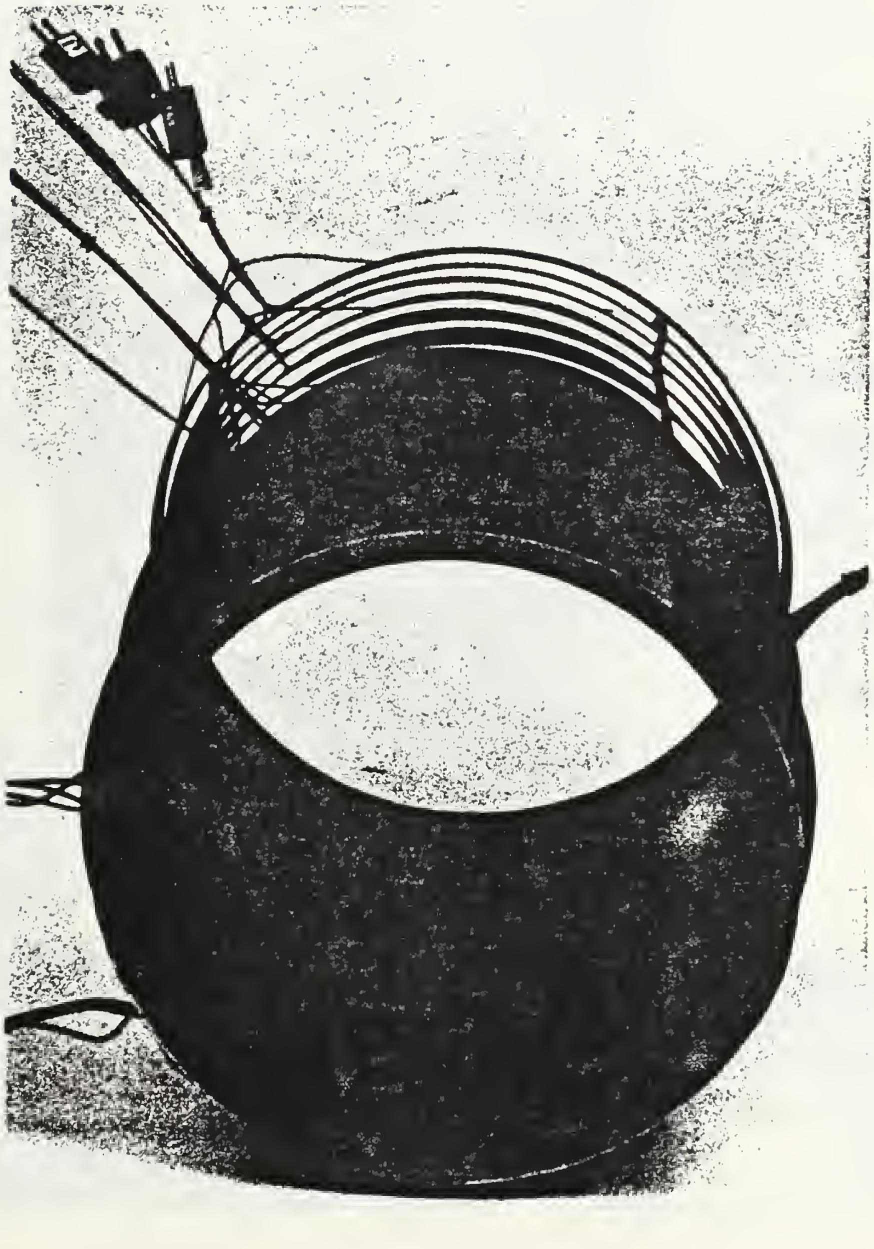


Figure 27. Model B Entrance

Figure 28. Model B Exit

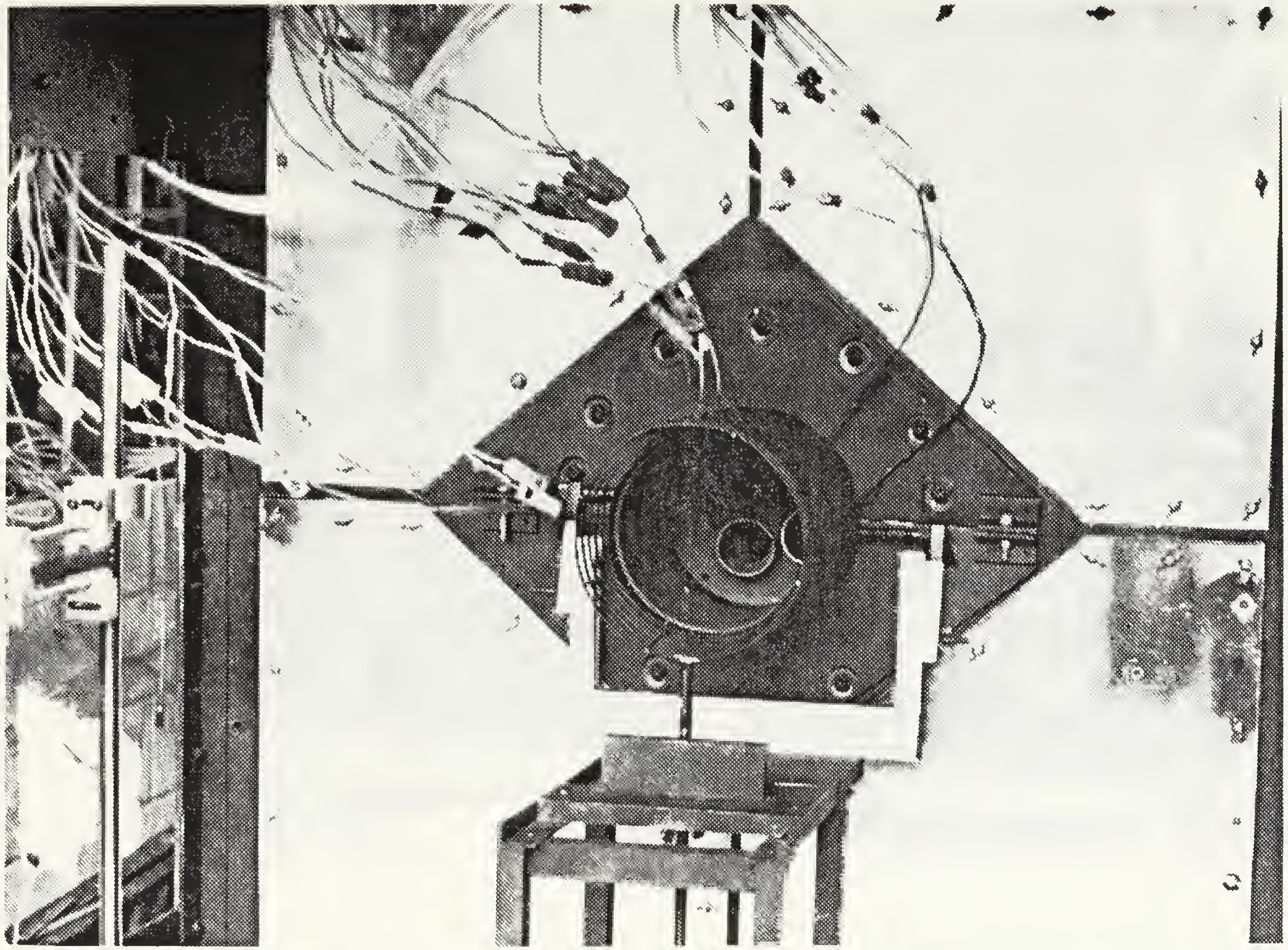


Figure 29. Typical Model Installation

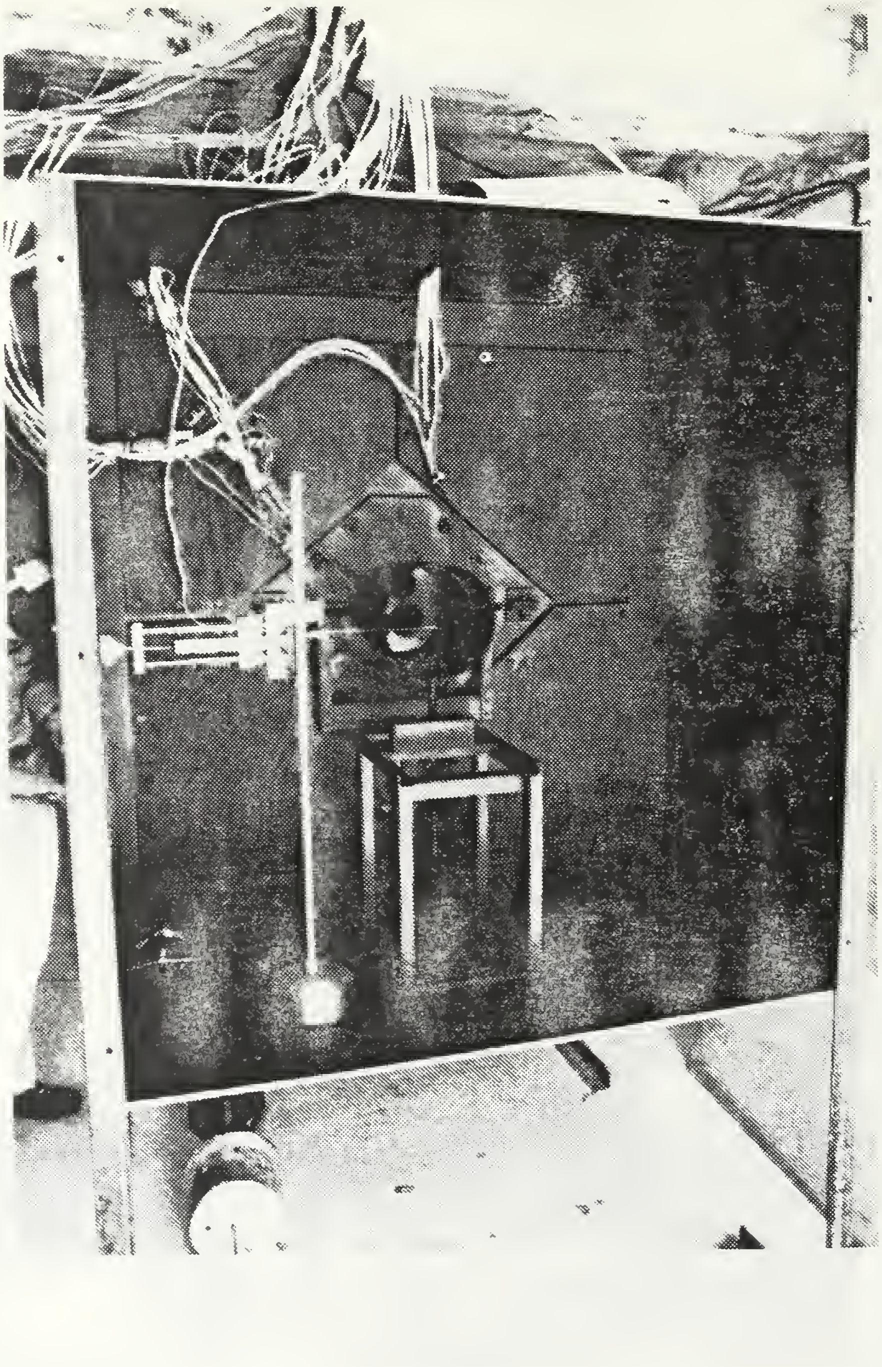


Figure 30. Exit Plane Temperature Measurement.

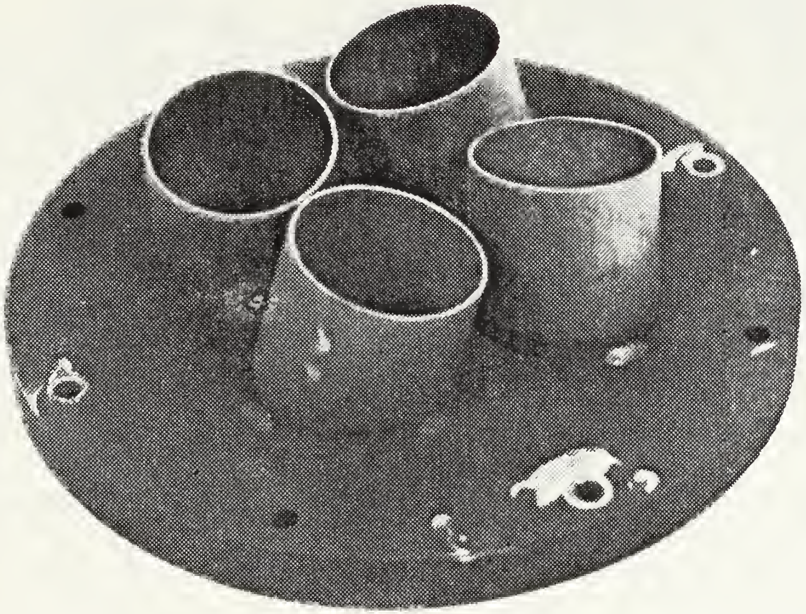


Figure 31. Tilted-Angled Nozzle Plate.

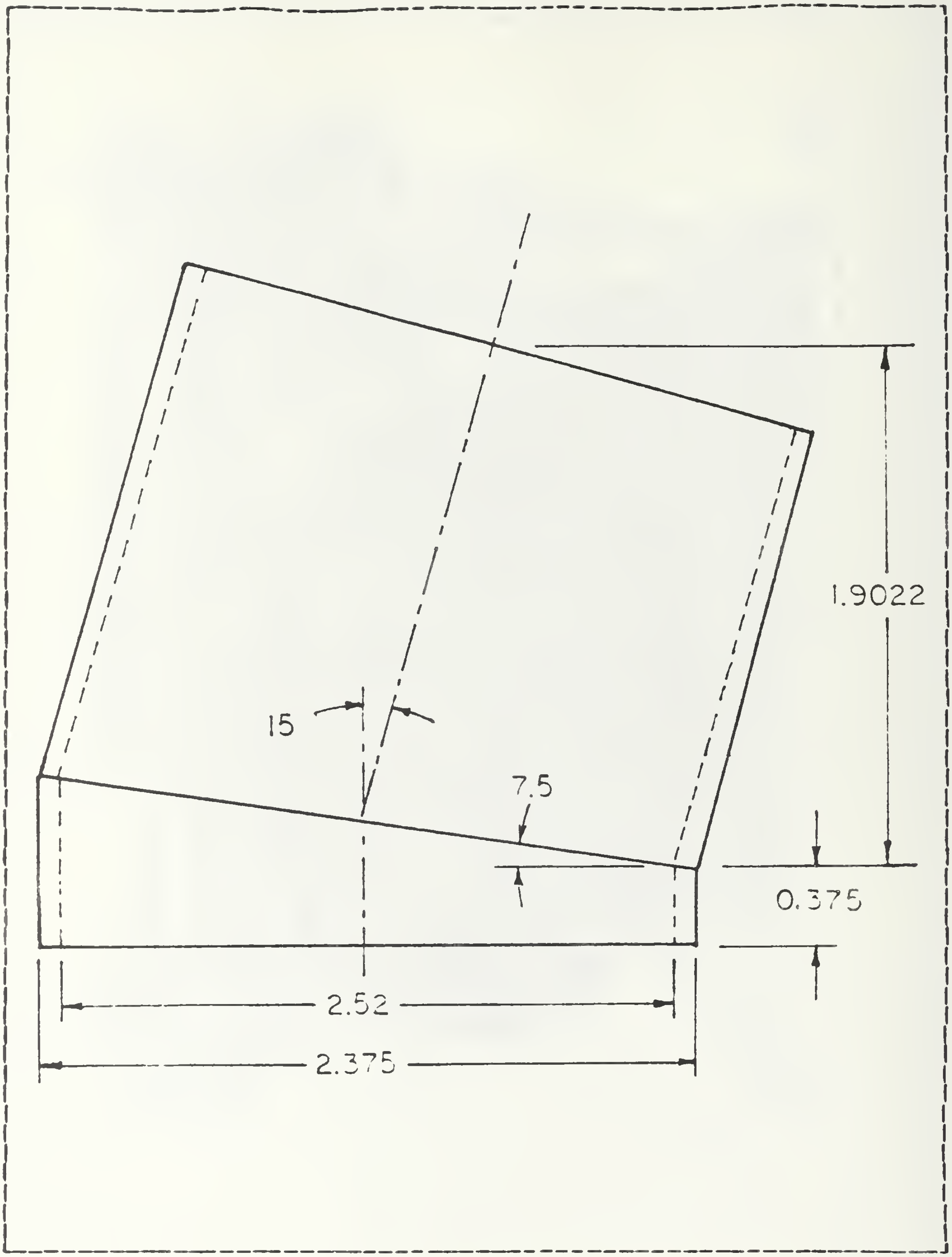


Figure 32. Tilted Nozzle Geometry.

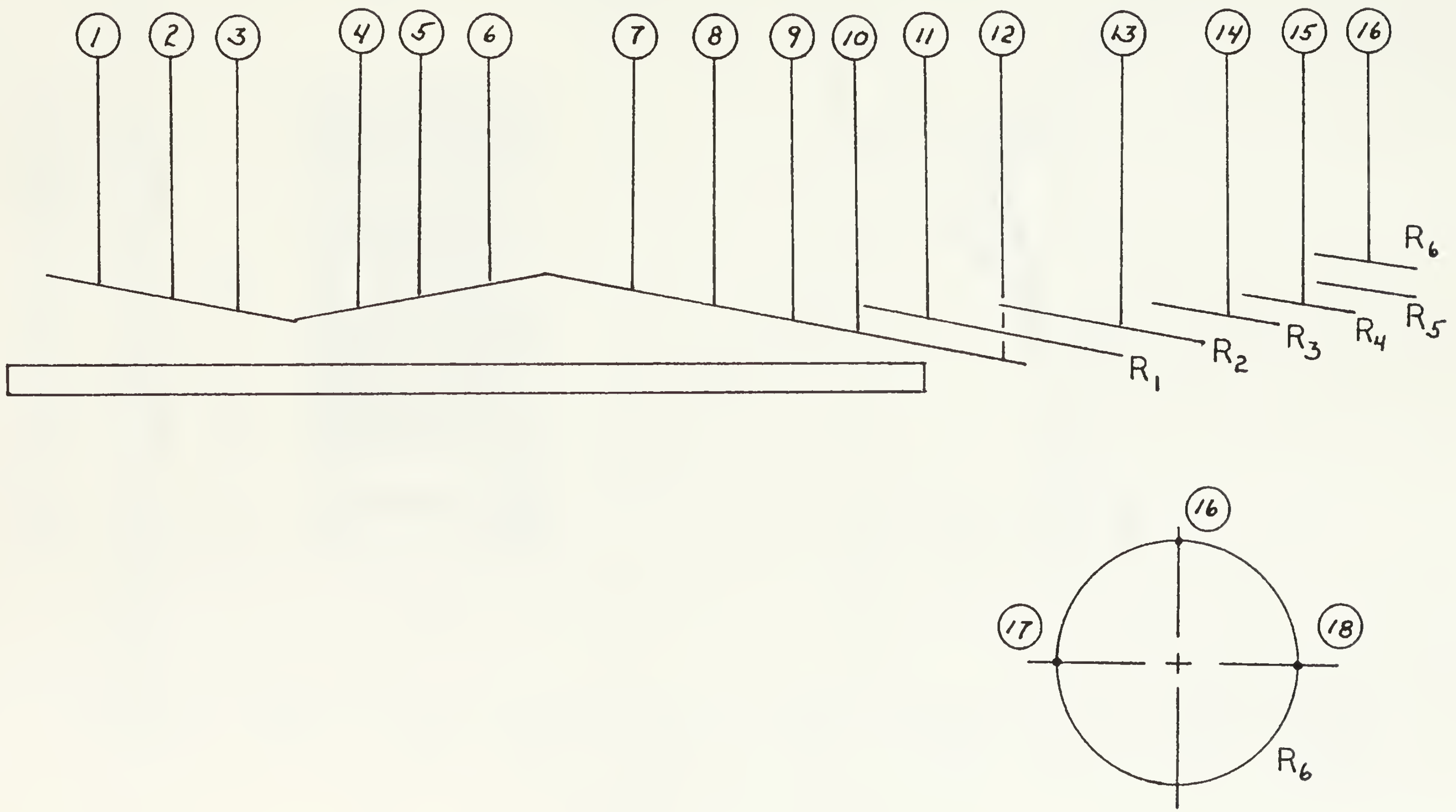
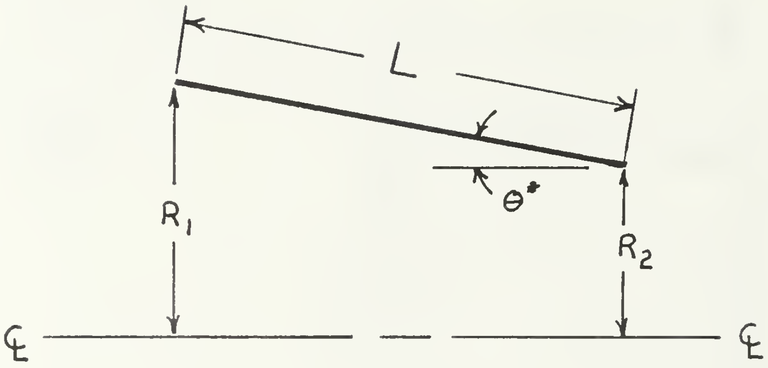


Figure 33. External Temperature Measurement Points



RING	R_1	R_2	L	L/D**
1	4.183	3.812	2.134	0.300
2	4.153	3.906	1.424	0.200
3	4.185	4.000	1.068	0.150
4	4.249	4.095	.890	0.125
5	4.295	4.171	.712	0.100
6	4.483	4.359	.712	0.100

*θ - Design = 10^{o}

**D - Mixing Tube Diameter

Figure 34. Diffuser Ring Specifications

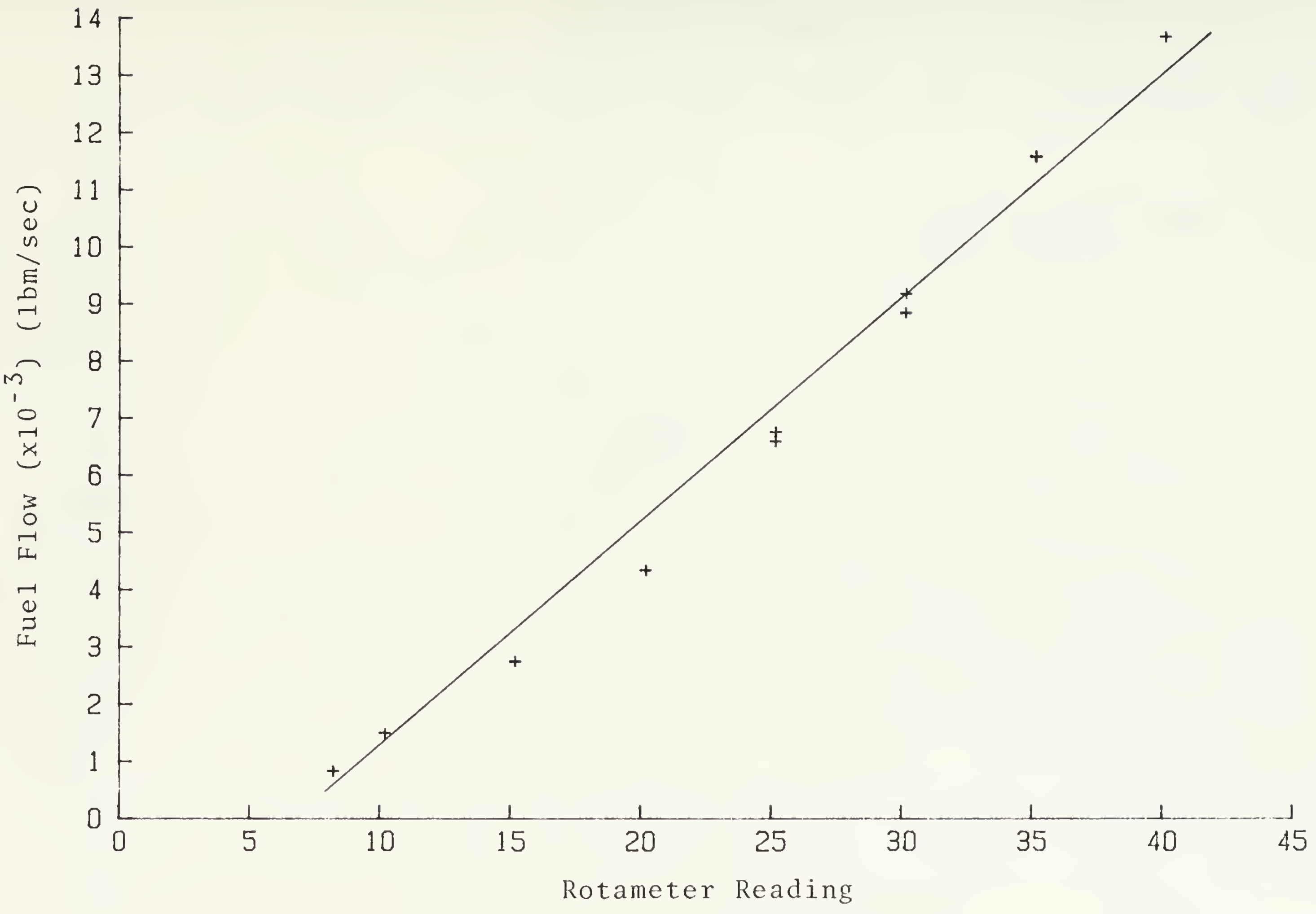


Figure 35. Rotameter Calibration Curve

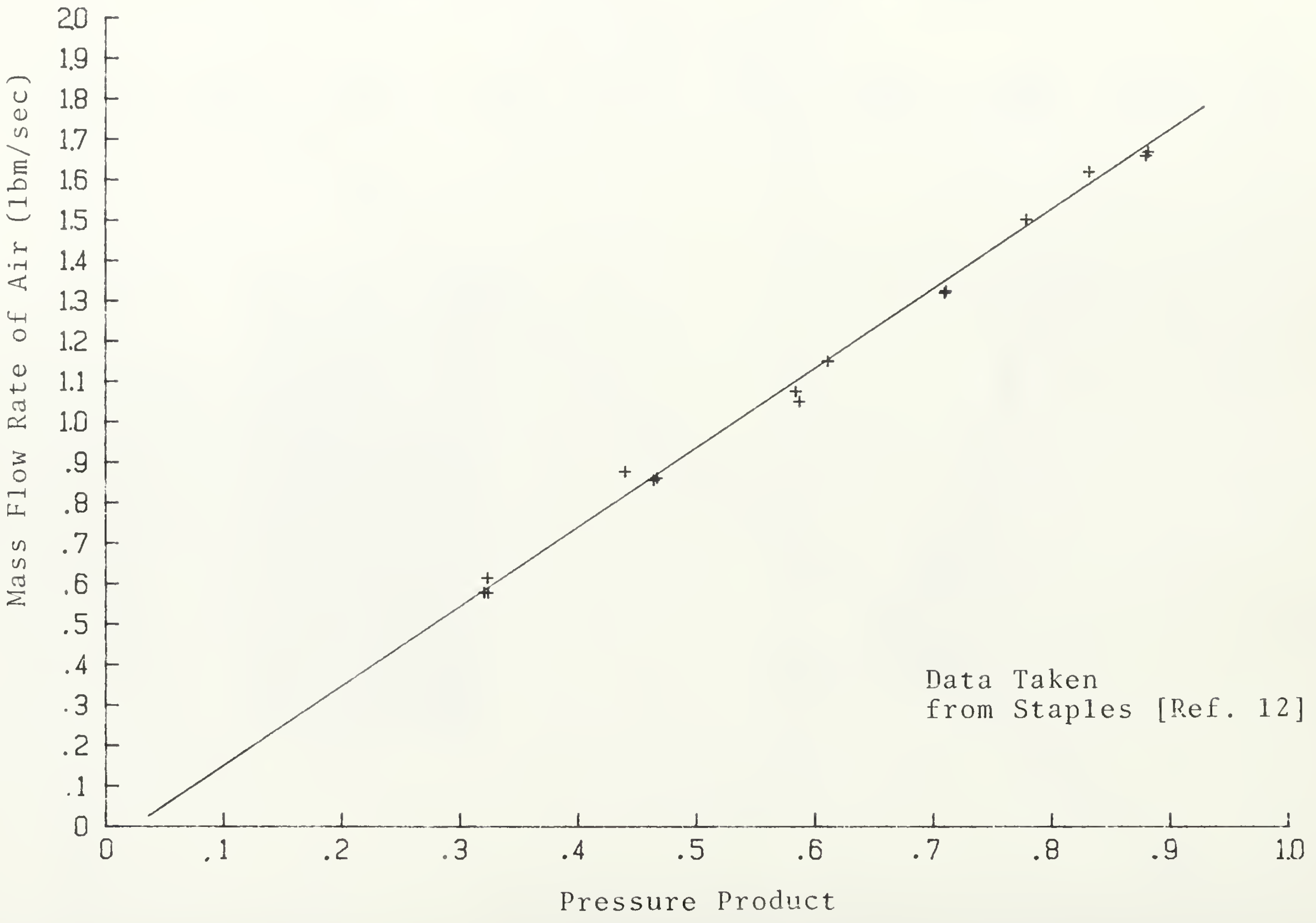


Figure 36. Air Mass Flow Calibration Curve

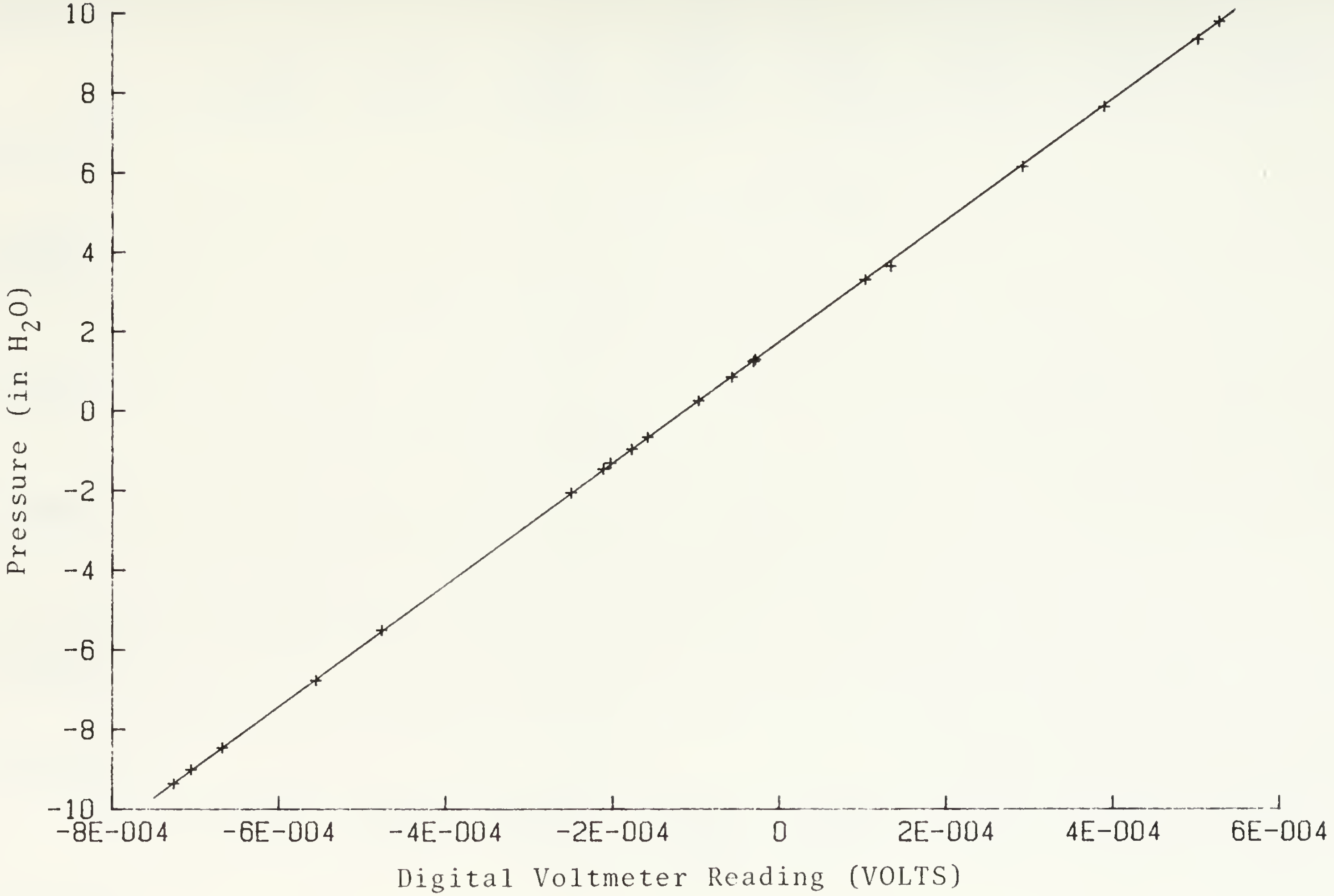


Figure 37. Scanivalve Pressure Transducer Calibration Curve

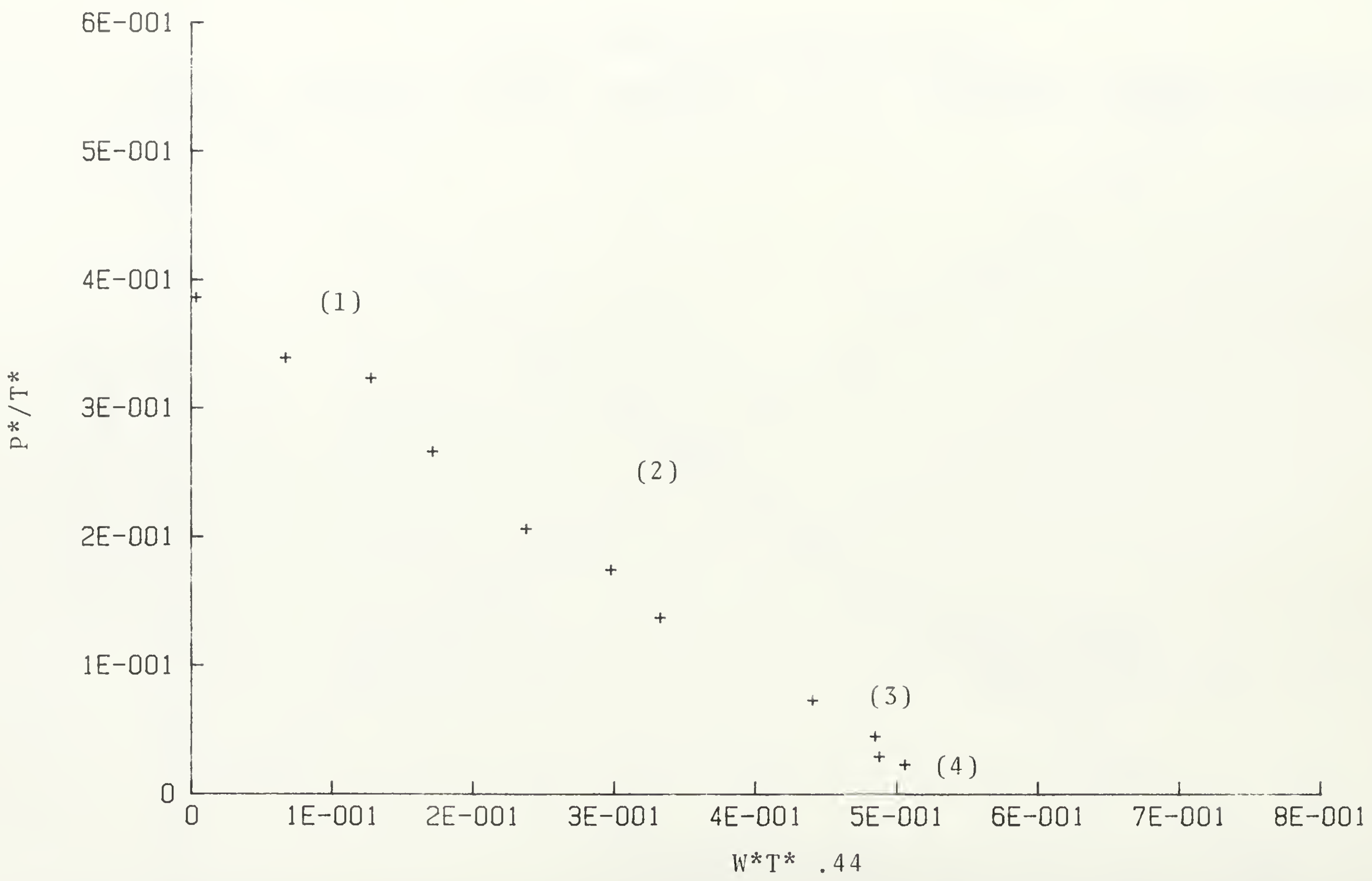


Figure 38. Pumping Coefficient, Model A Mod ($175^{O}F$)

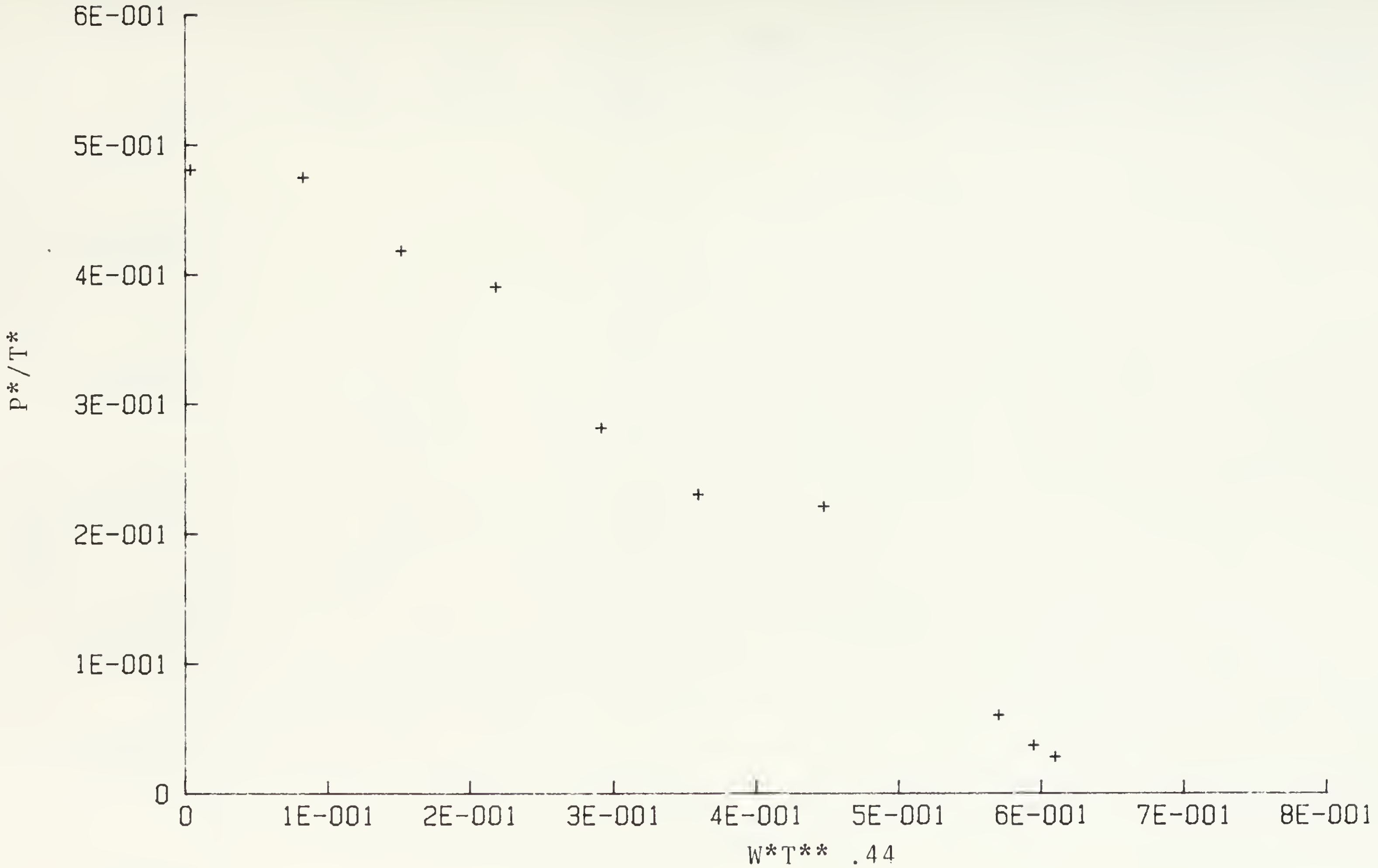


Figure 39. Pumping Coefficient, Model A Mod (950°F)

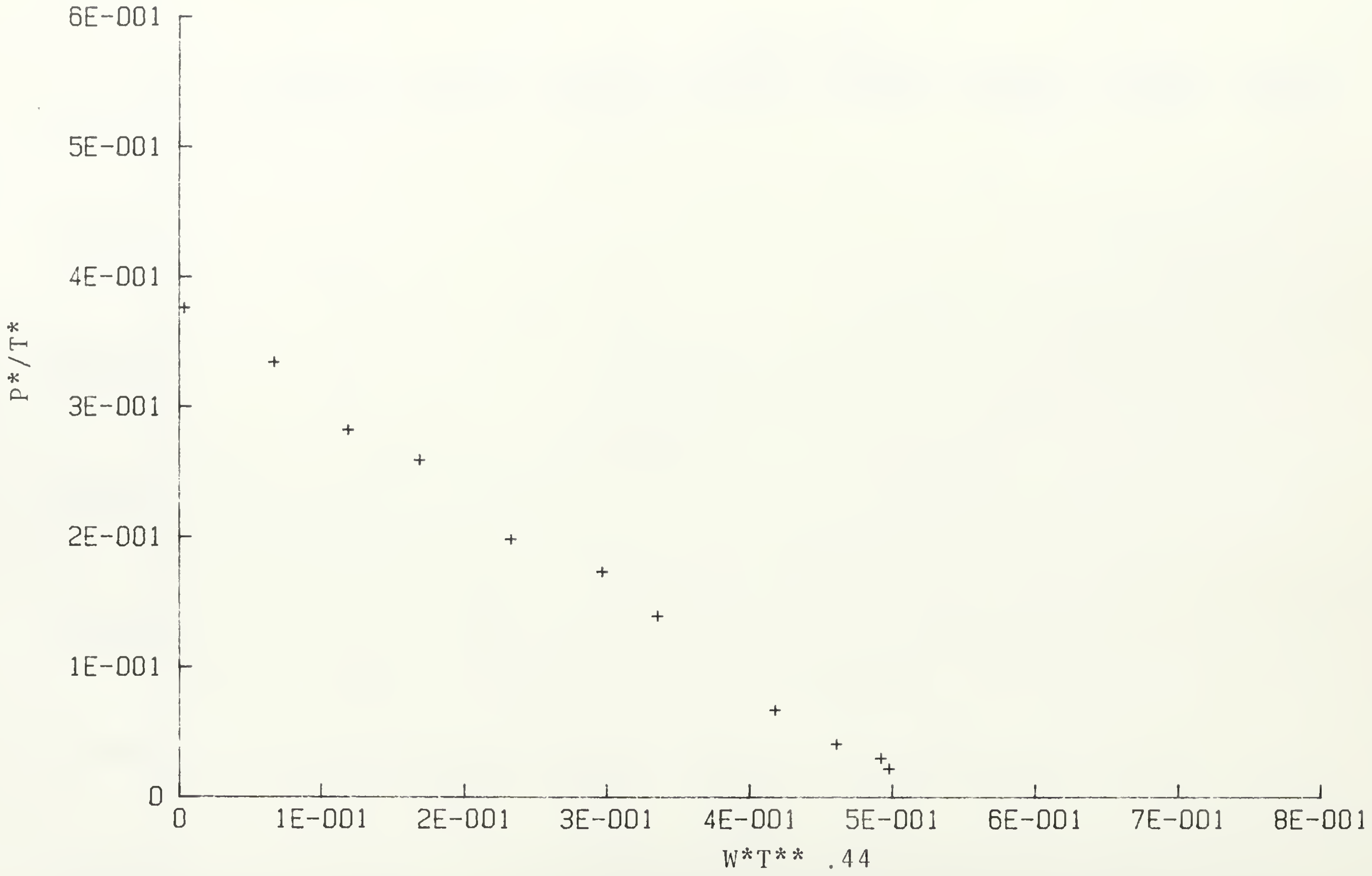


Figure 40. Pumping Coefficient, Model B (175°F), M=.06

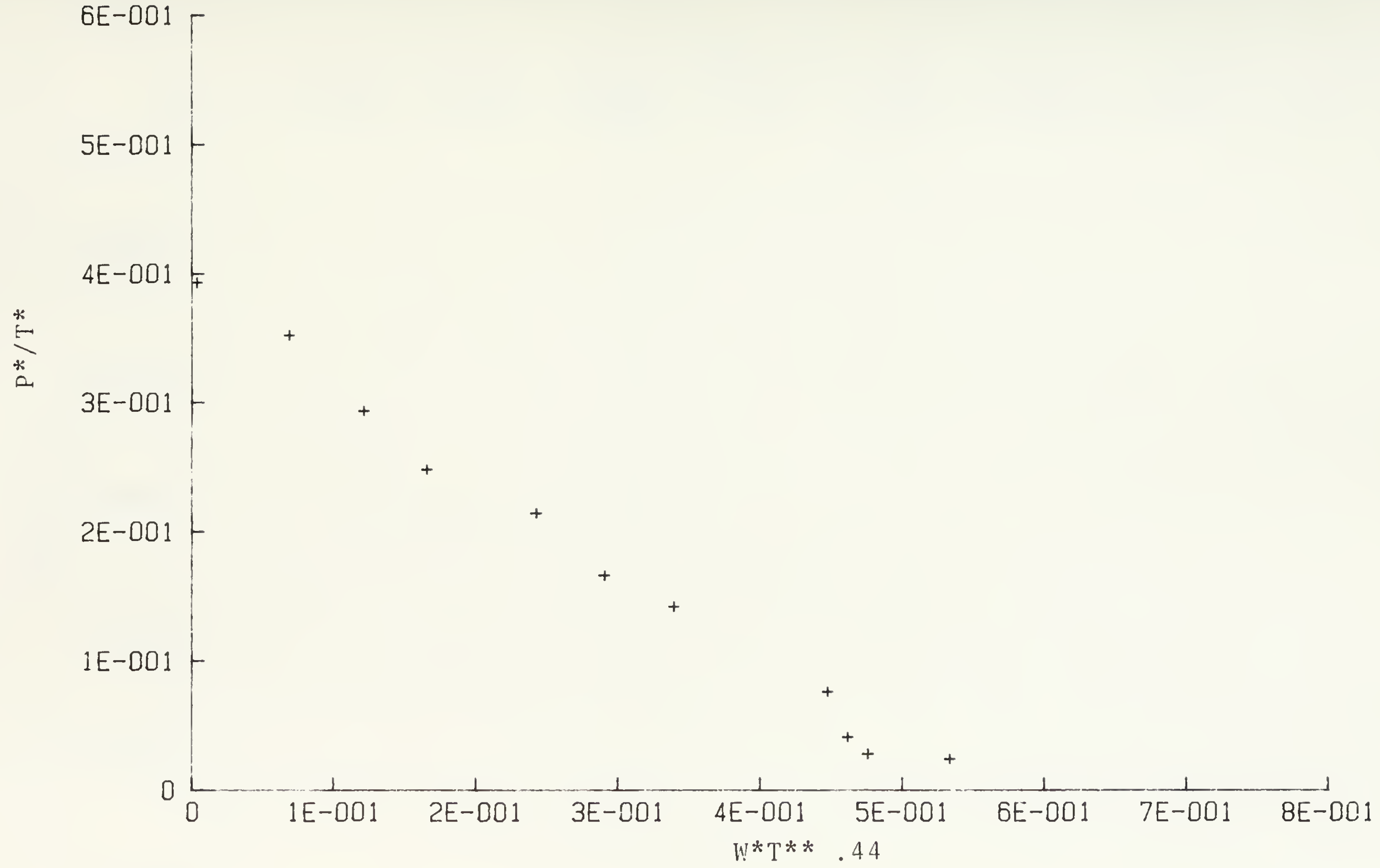


Figure 41. Pumping Coefficient, Model B (175°F), M=.058

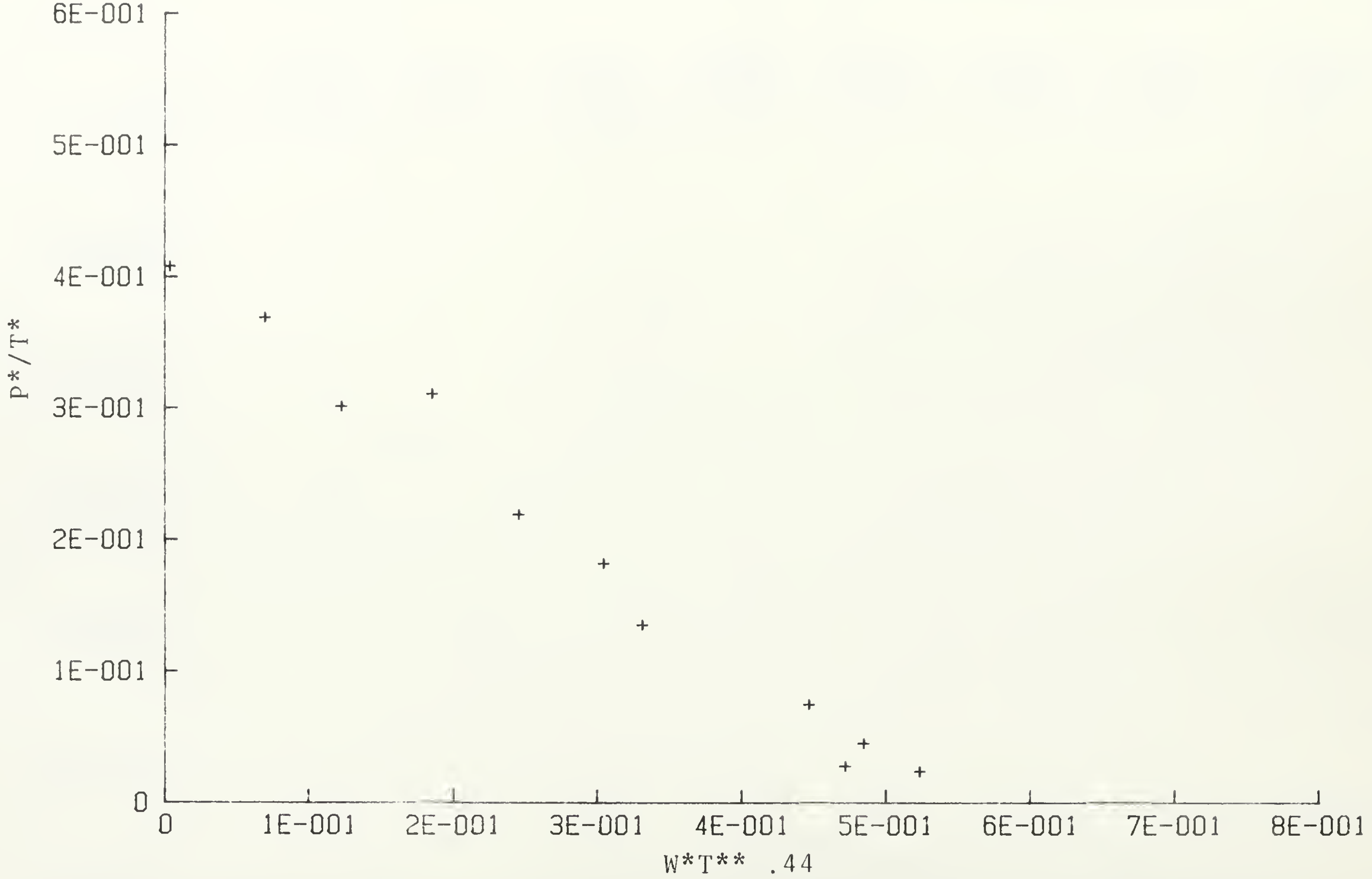


Figure 42. Pumping Coefficient, Model B (175^{o}F), M=.048

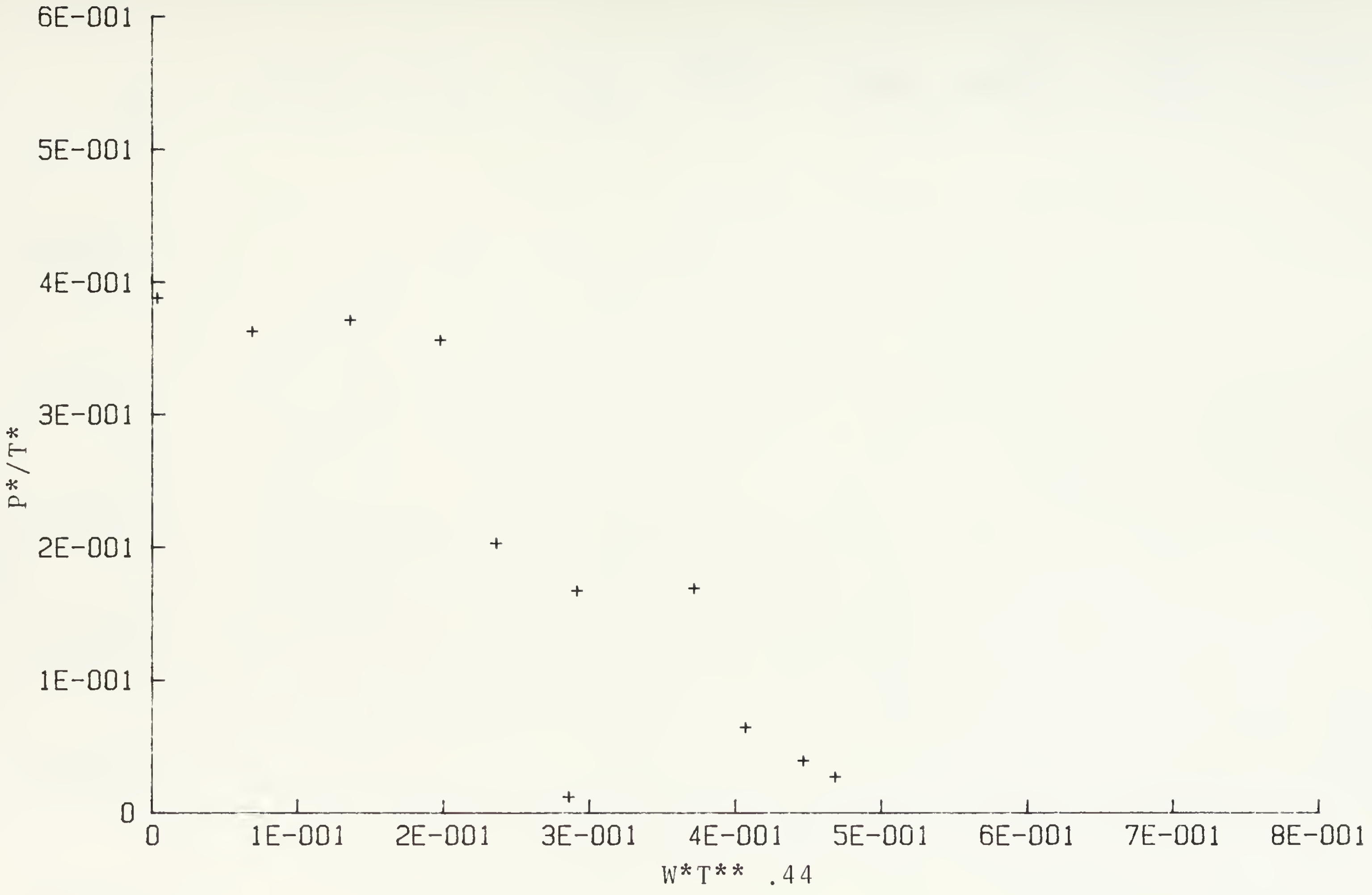


Figure 43. Pumping Coefficient, Model B (175^{o}F), M=.036

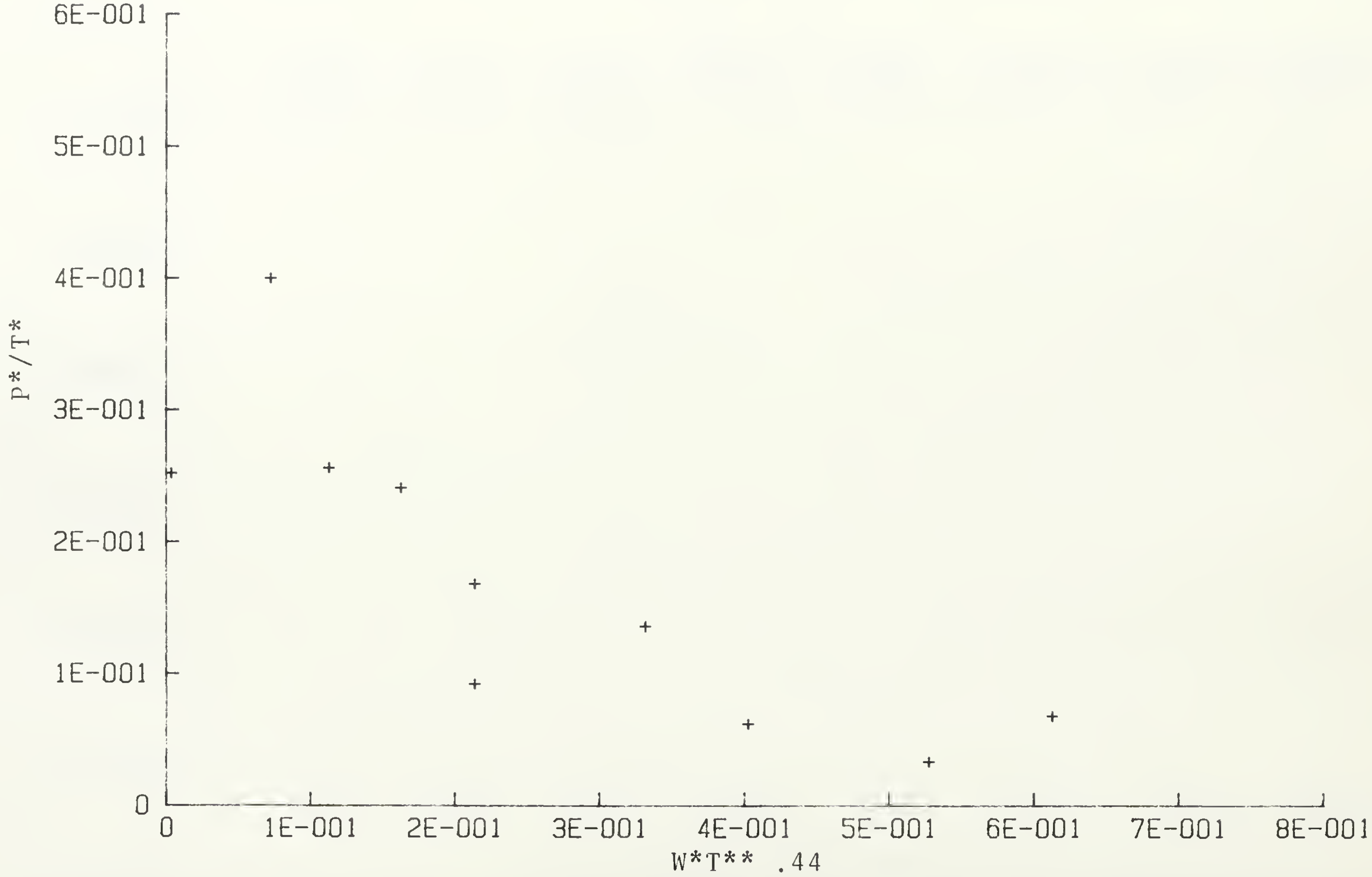


Figure 44. Pumping Coefficient, Model B (175°F), M=.027

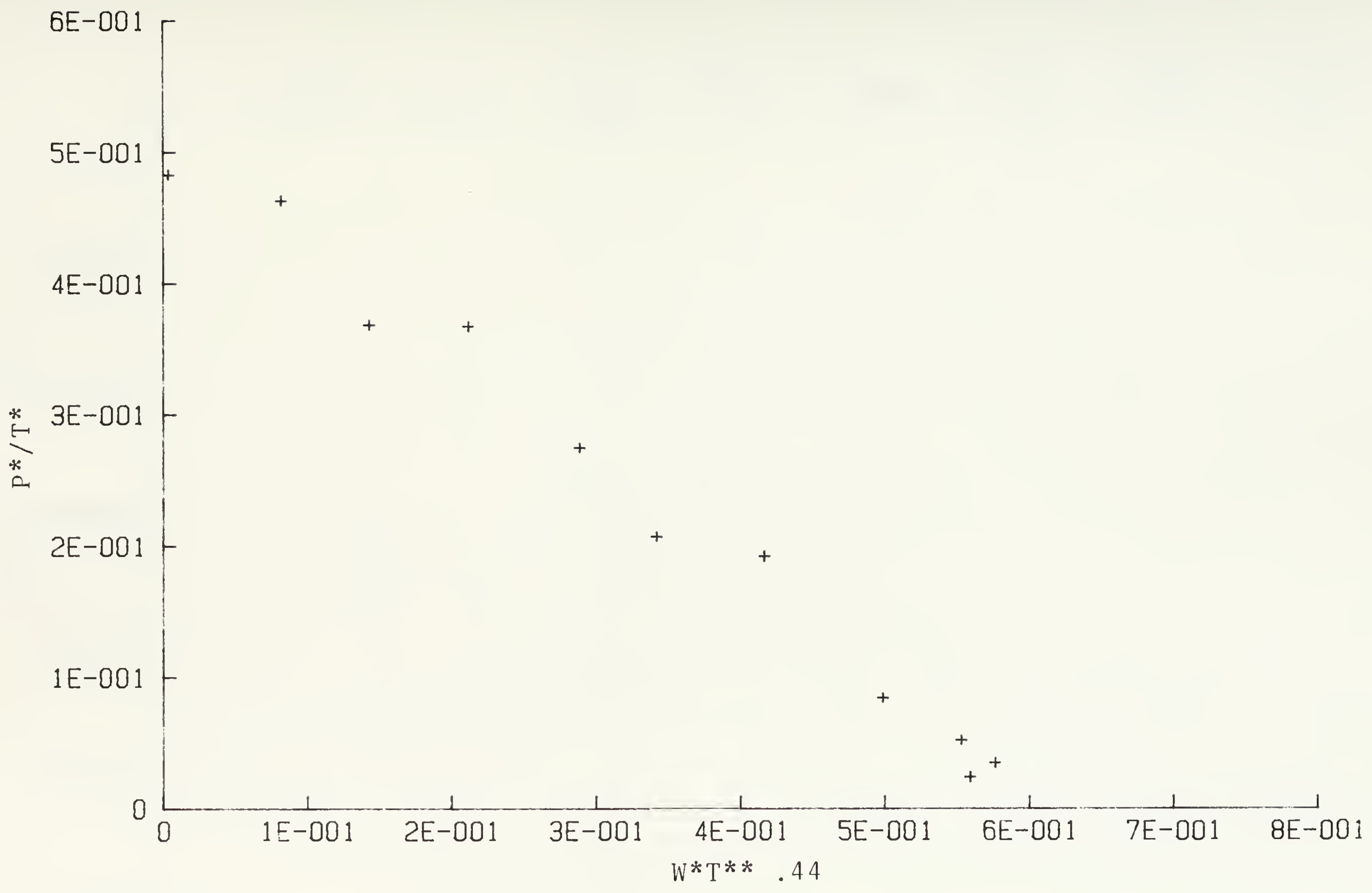


Figure 45. Pumping Coefficient, Model B ($950^{o}F$), M=.06

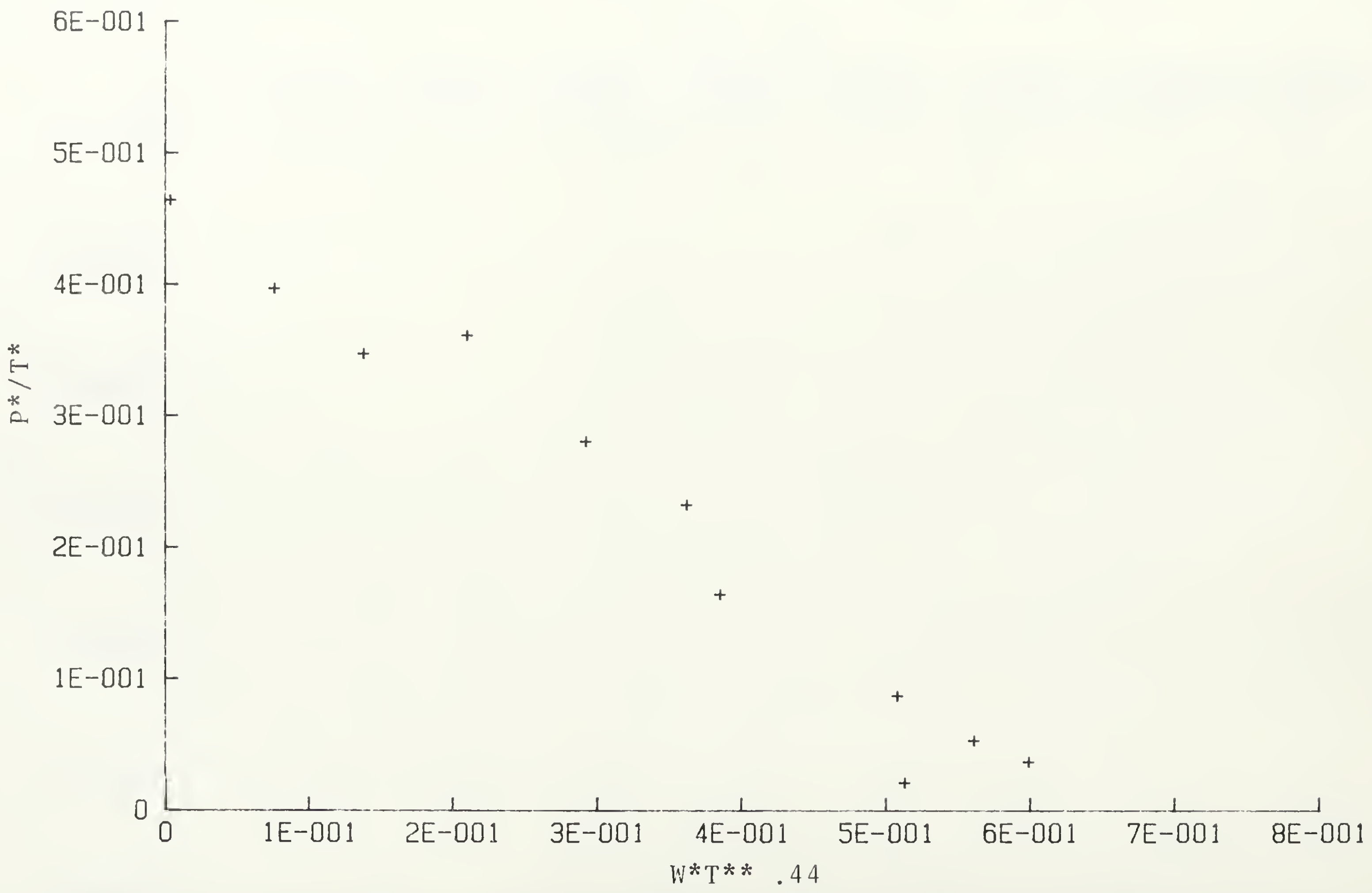


Figure 46. Pumping Coefficient, Model B (950^{o}F), M=.053

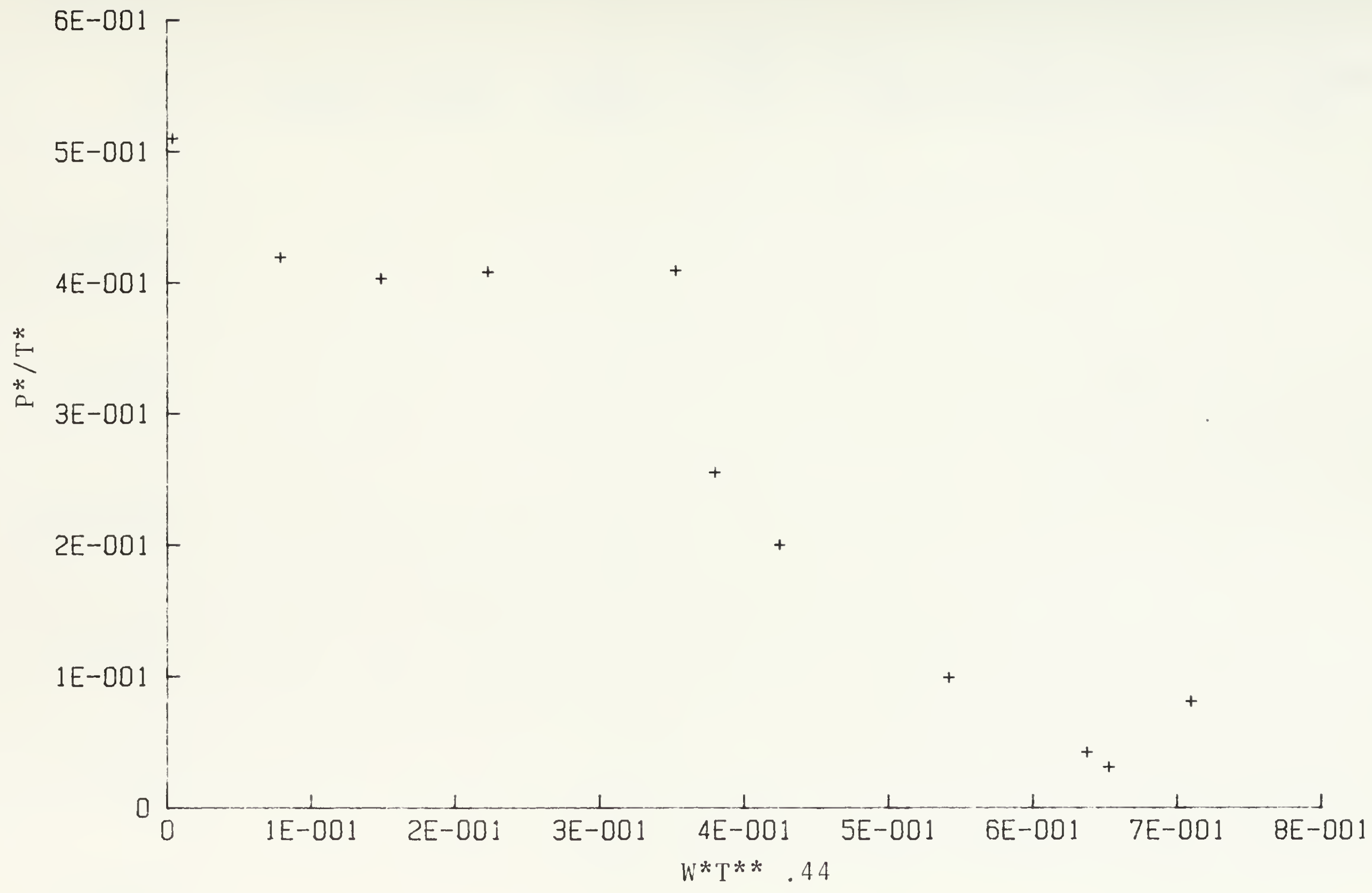


Figure 47. Pumping Coefficient, Model B (950°F), M=.047

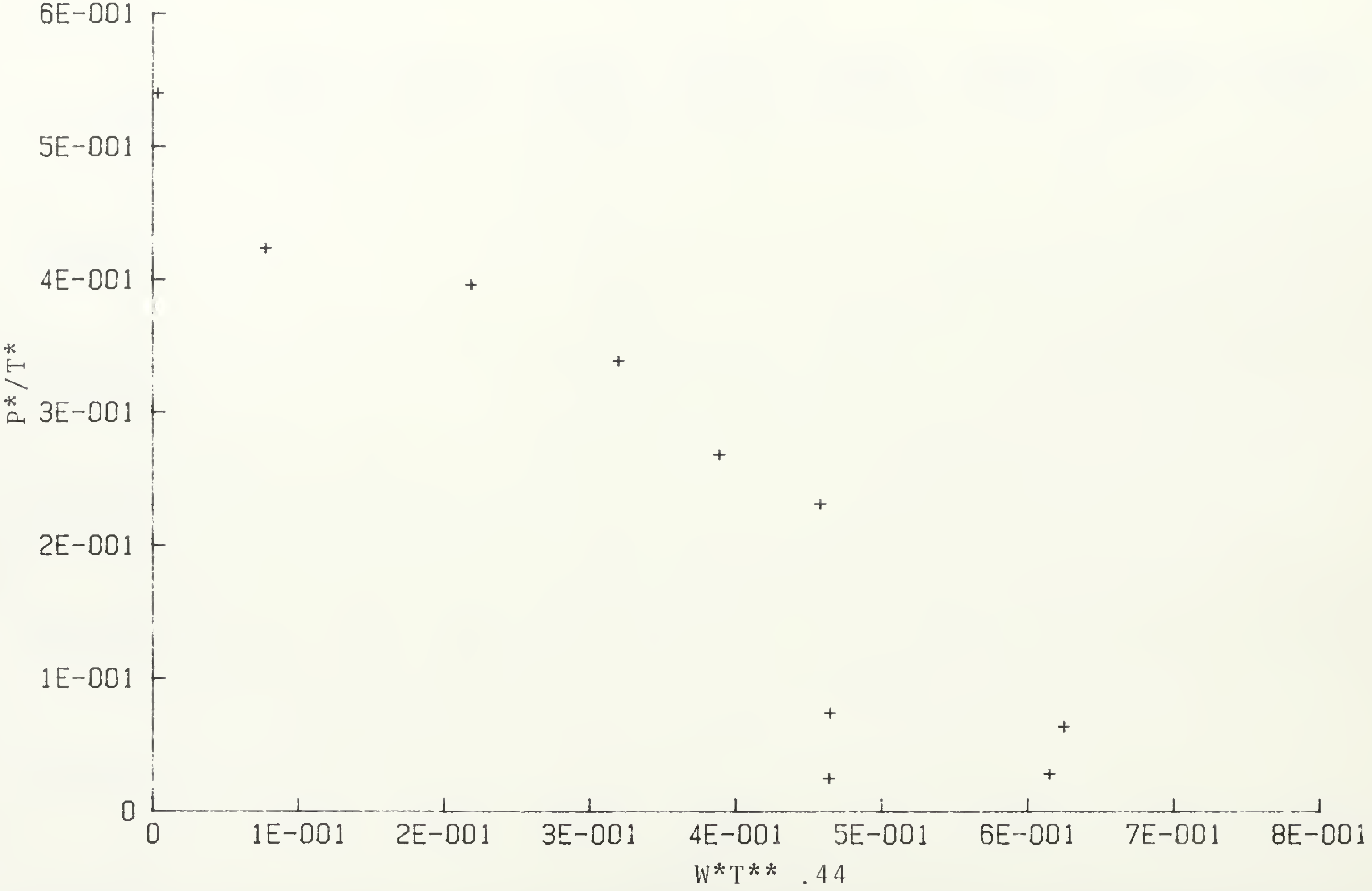


Figure 48. Pumping Coefficient, Model B (950^{O}F), M=.036

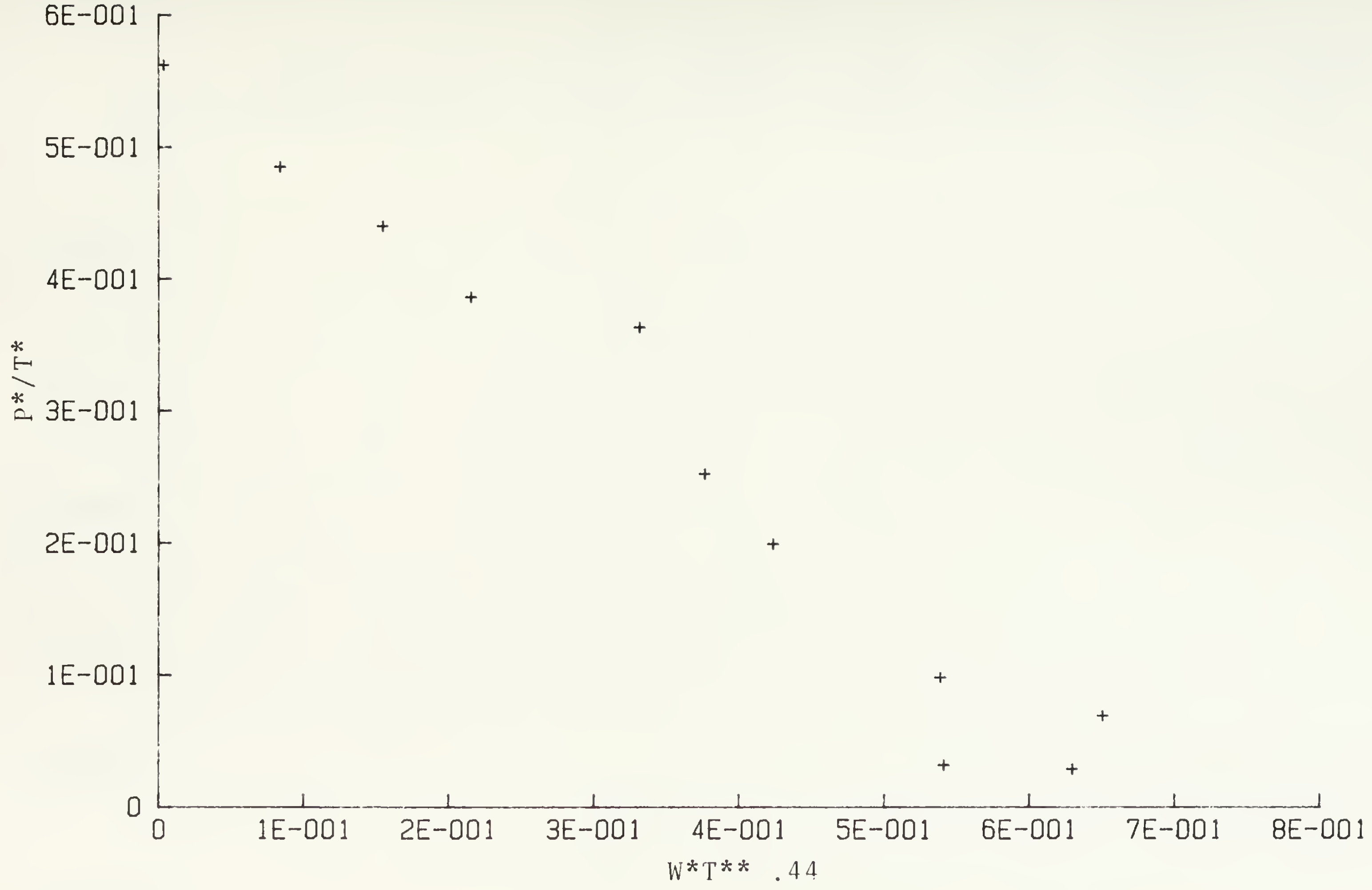


Figure 49. Pumping Coefficient, Model B ($950^{o}F$), M=.032

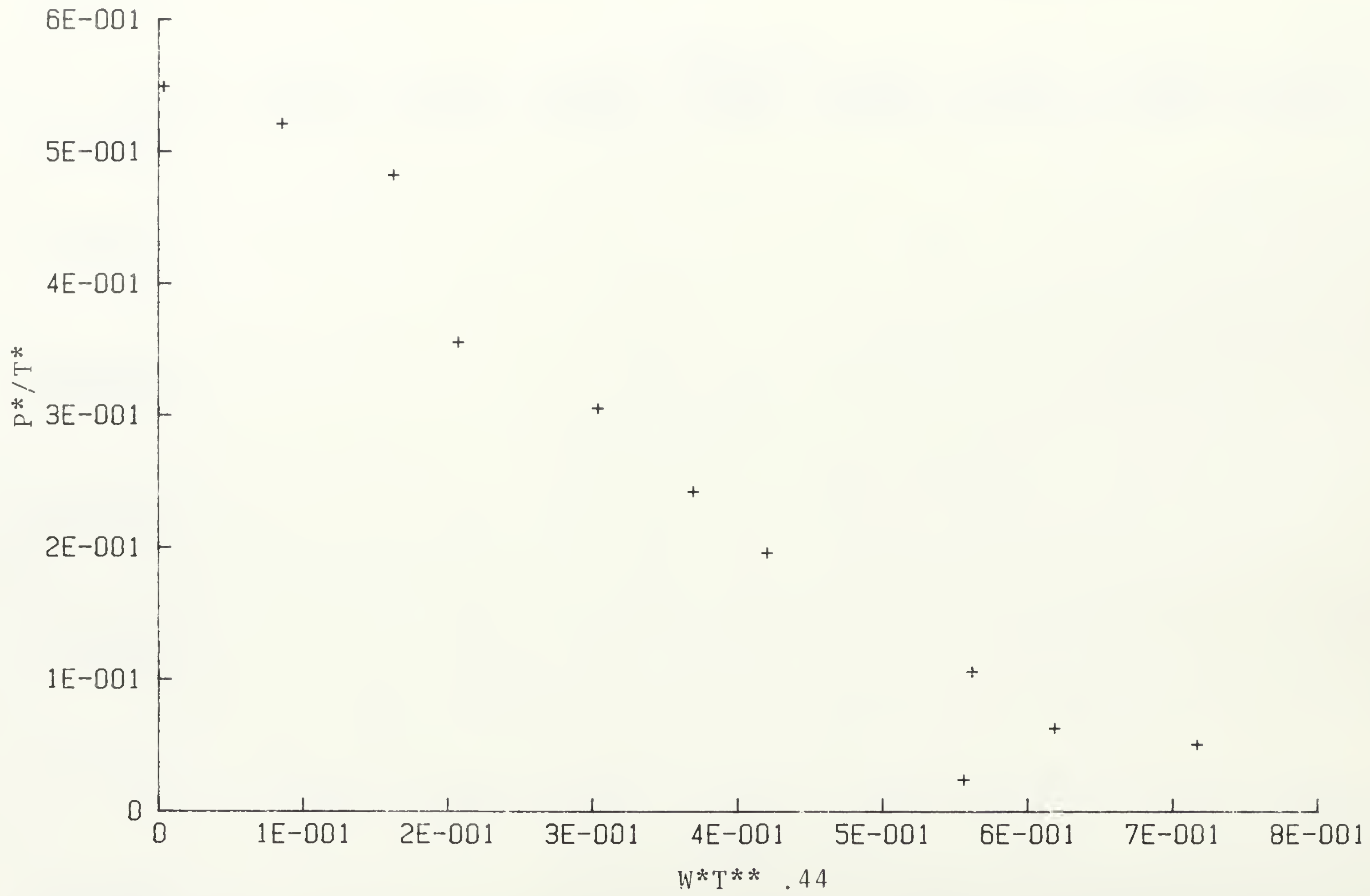


Figure 50. Pumping Coefficient, Model B (950^{O}F), M=.029

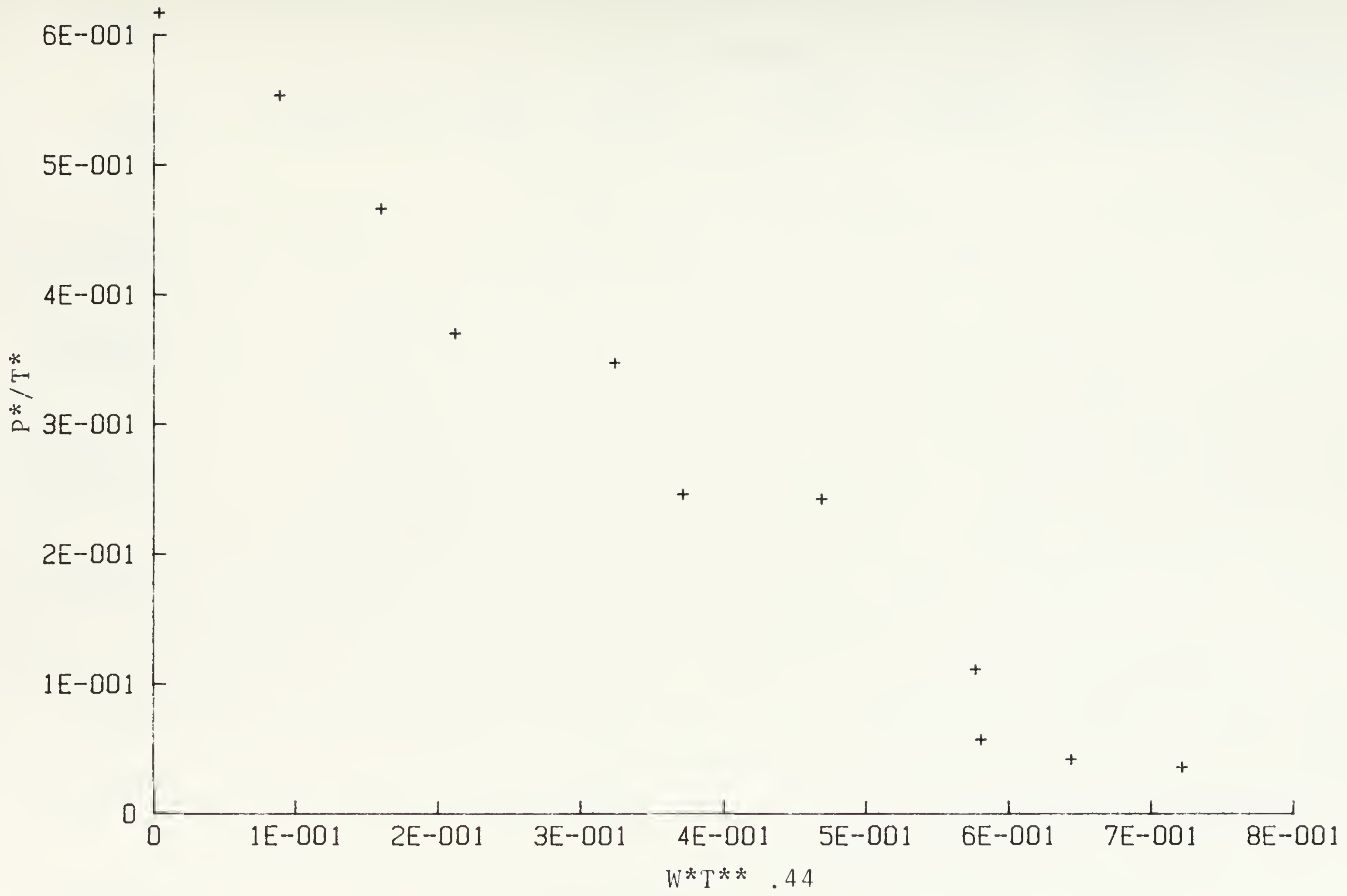


Figure 51. Pumping Coefficient, Model B (950^{o}F), M=.024

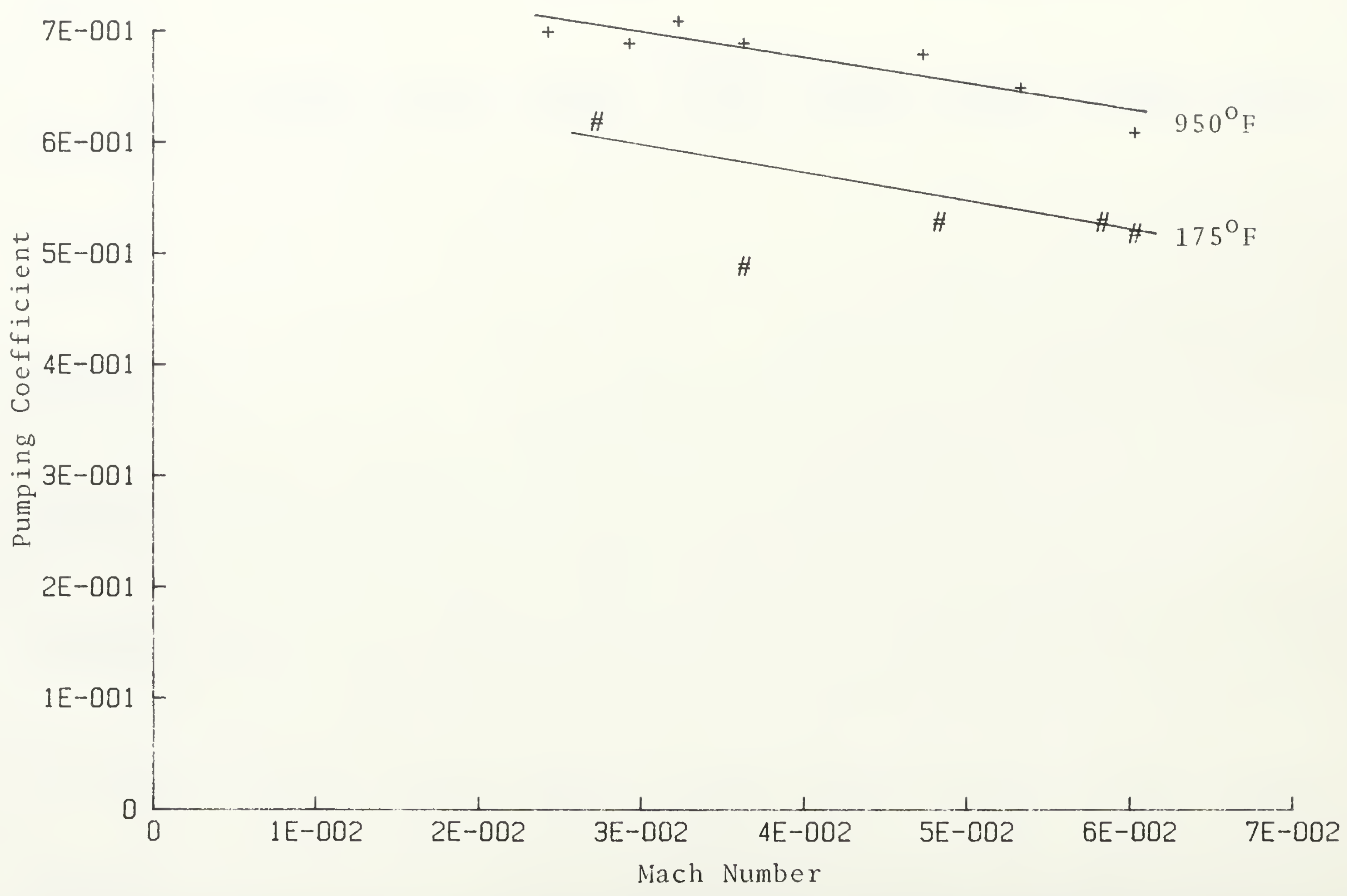


Figure 52. Pumping Coefficient vs Mach Number Curve

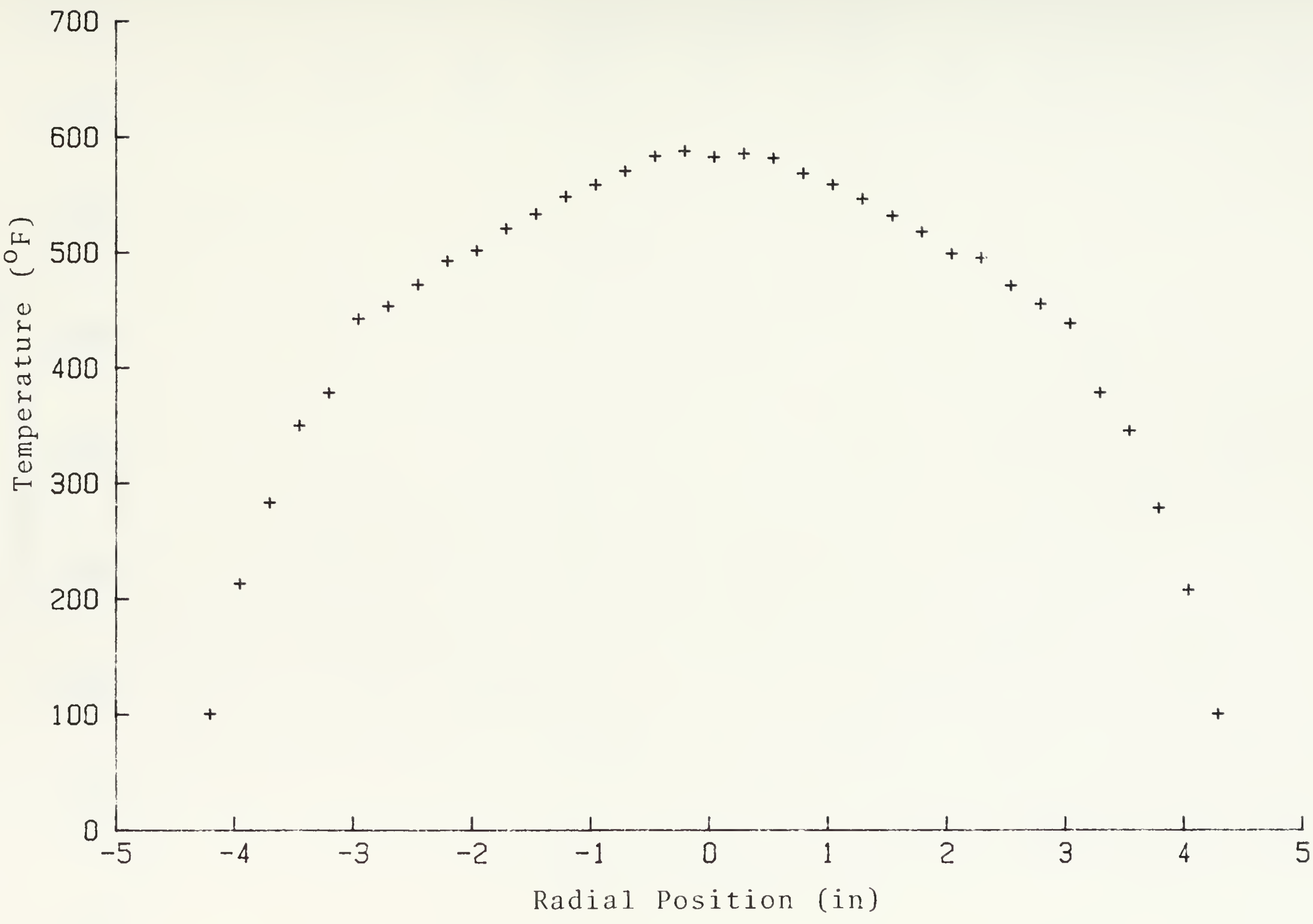


Figure 53. Exit Plane Temperature Profile (950^{o}F), M=.06

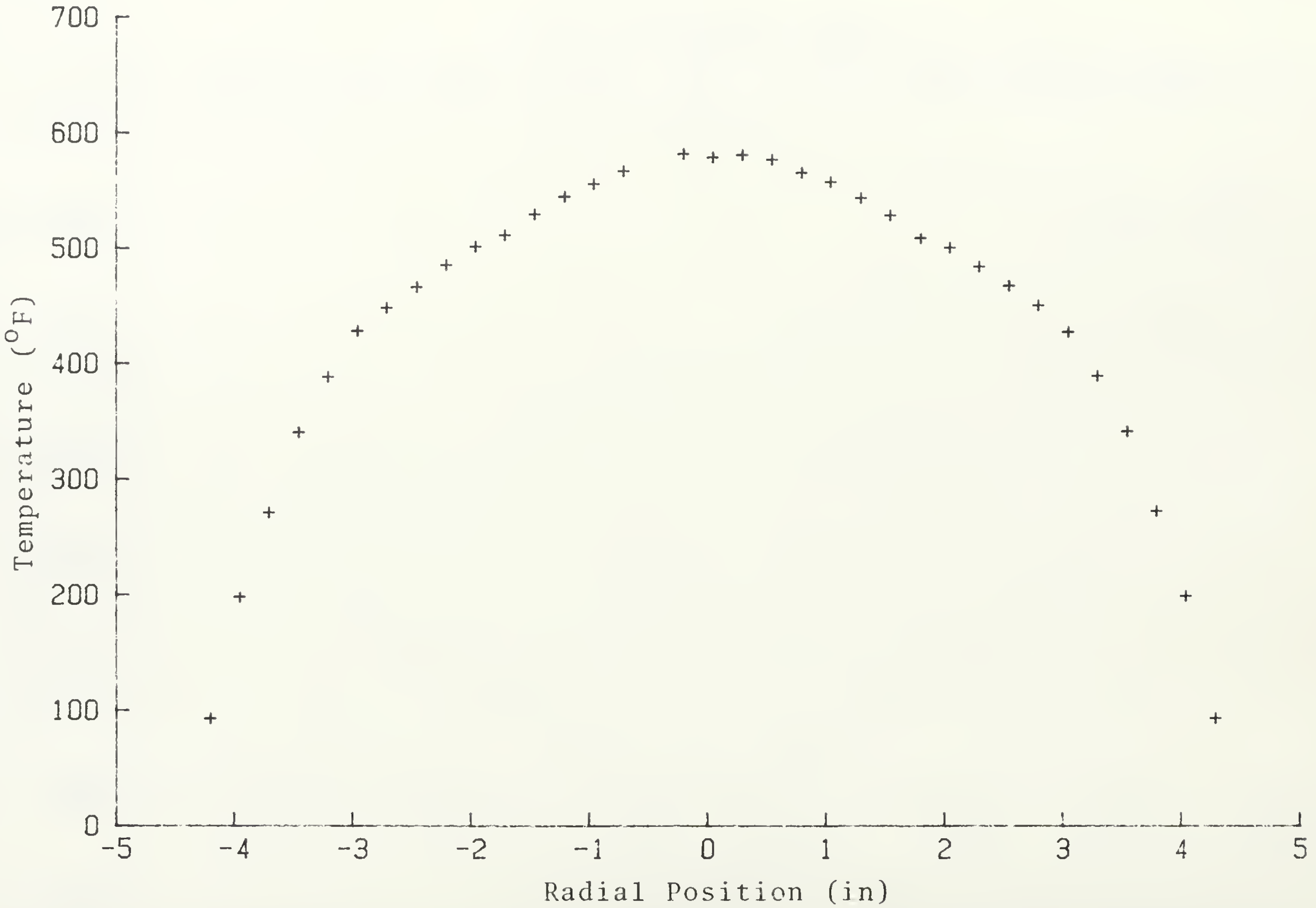


Figure 54. Exit Plane Temperature Profile (950^oF), M=.053

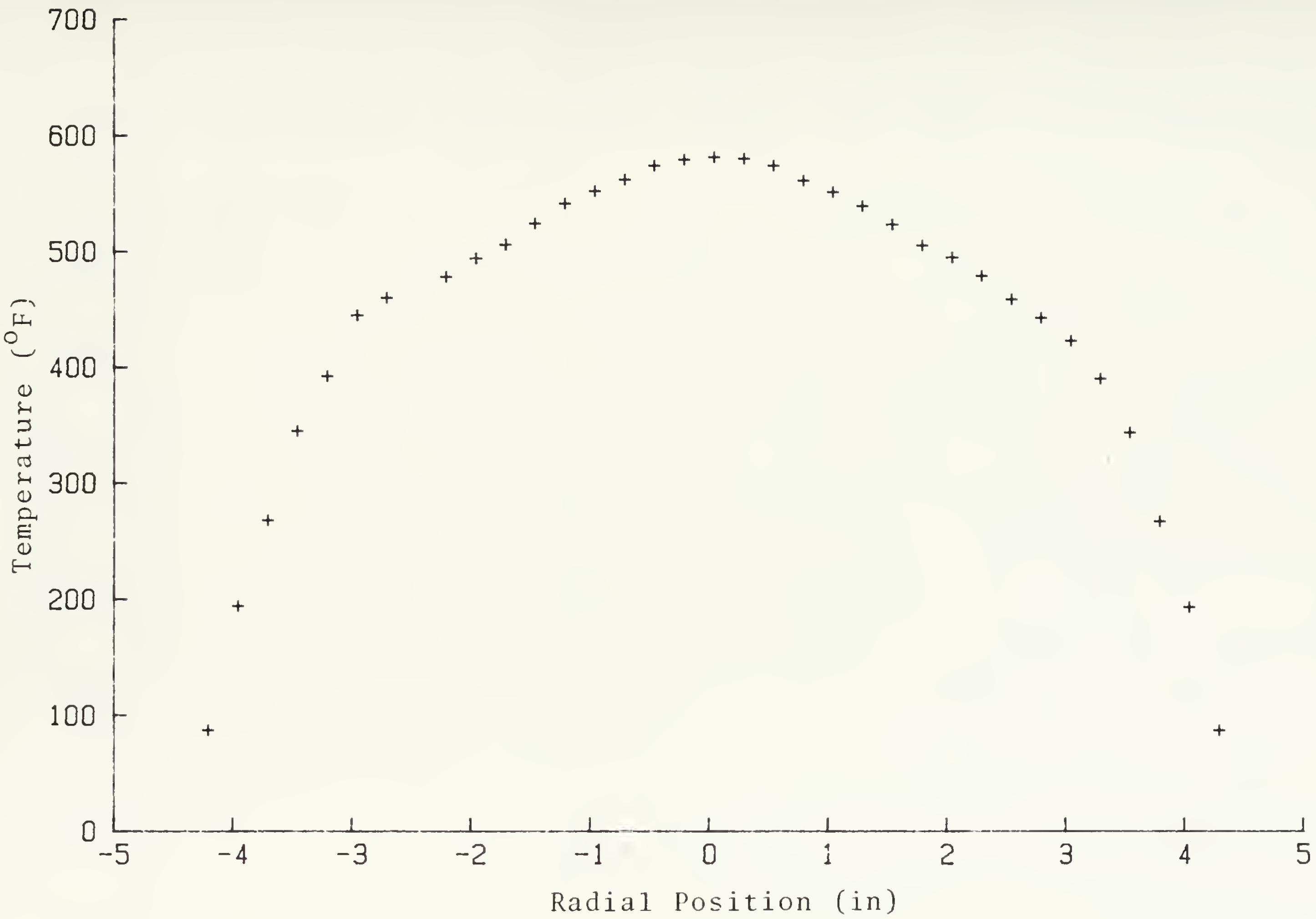


Figure 55. Exit Plane Temperature Profile (950°F), M=.047

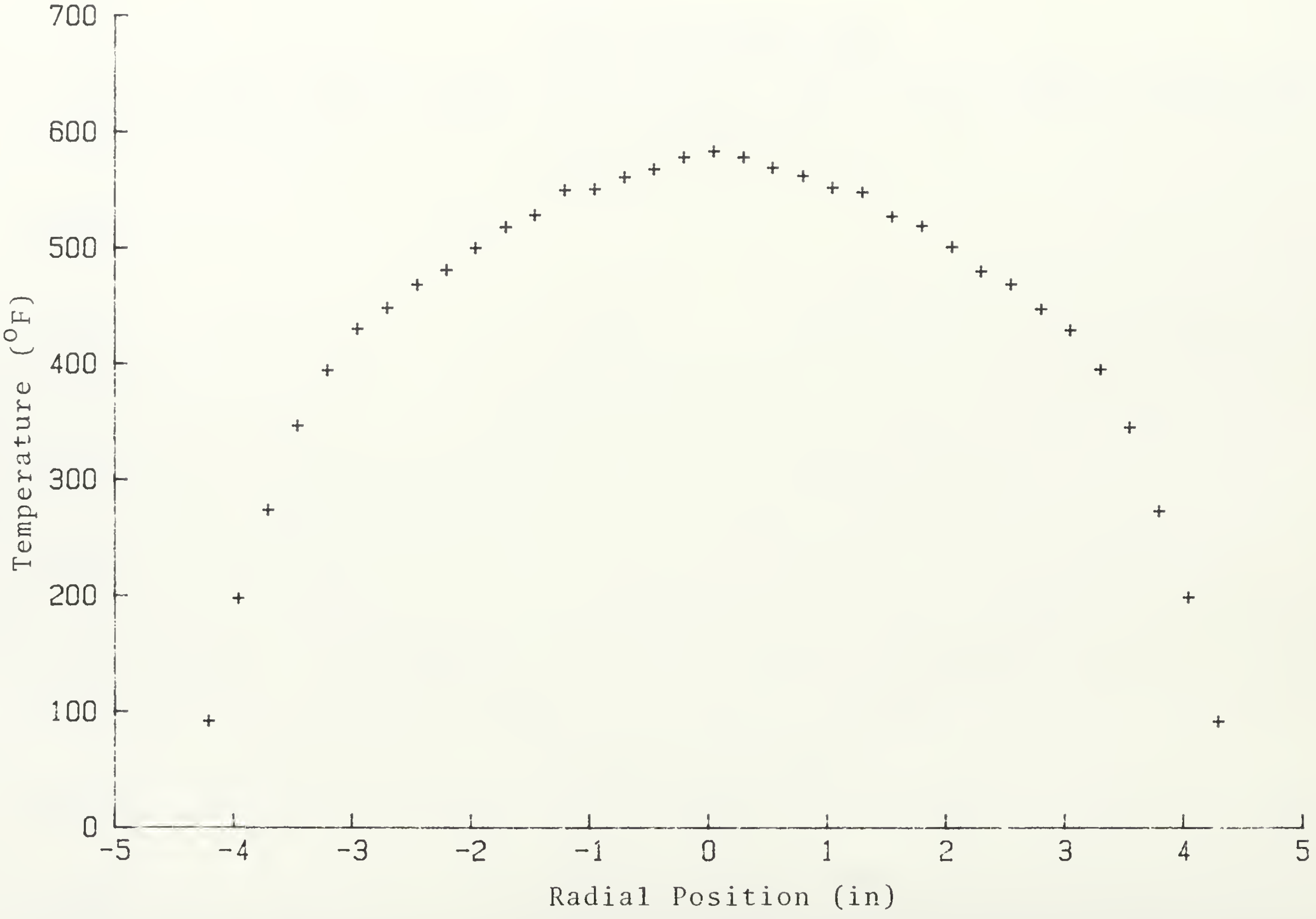


Figure 56. Exit Plane Temperature Profile (950°F), M=.036

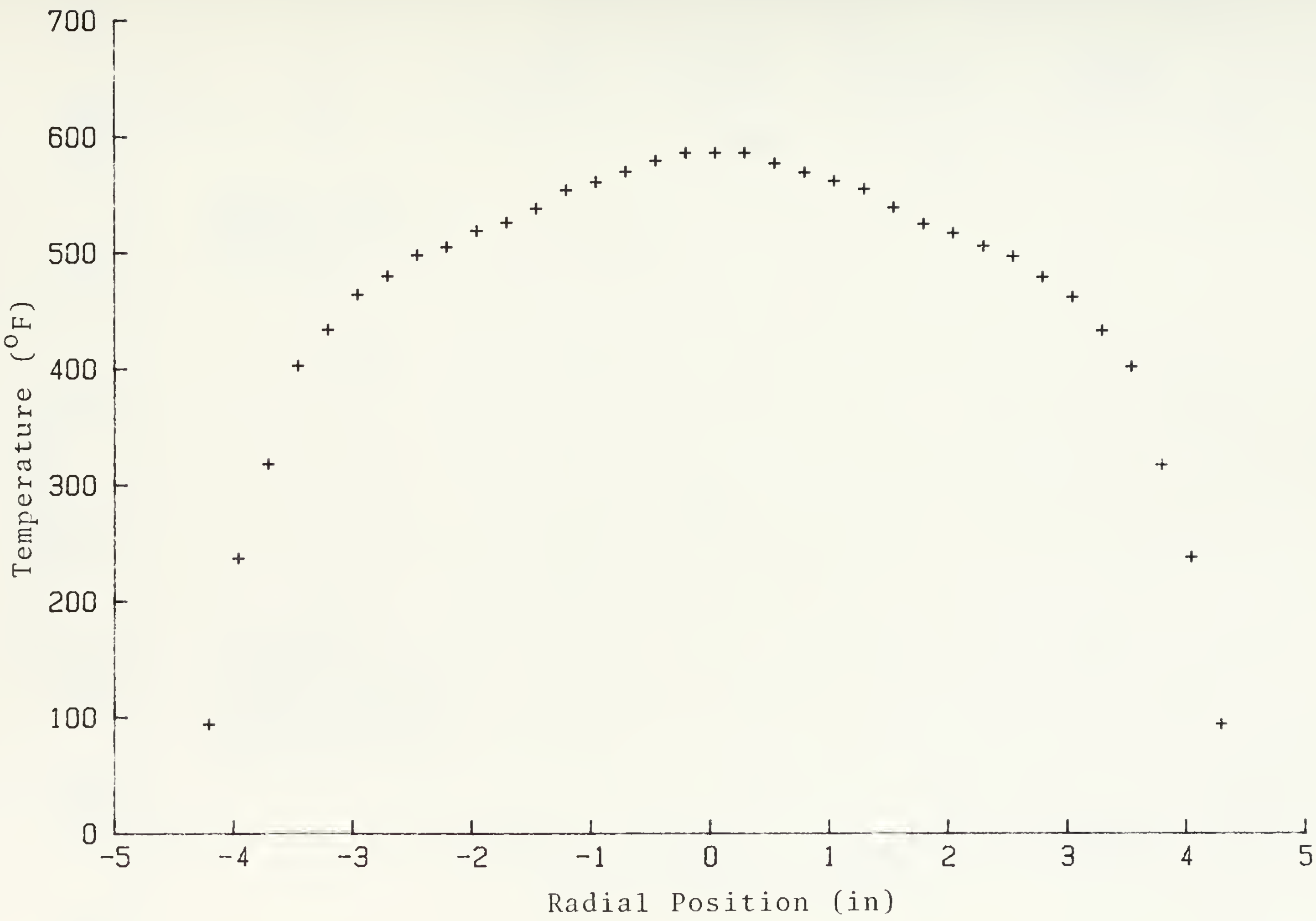


Figure 57. Exit Plane Temperature Profile (950^{o}F), M=.024

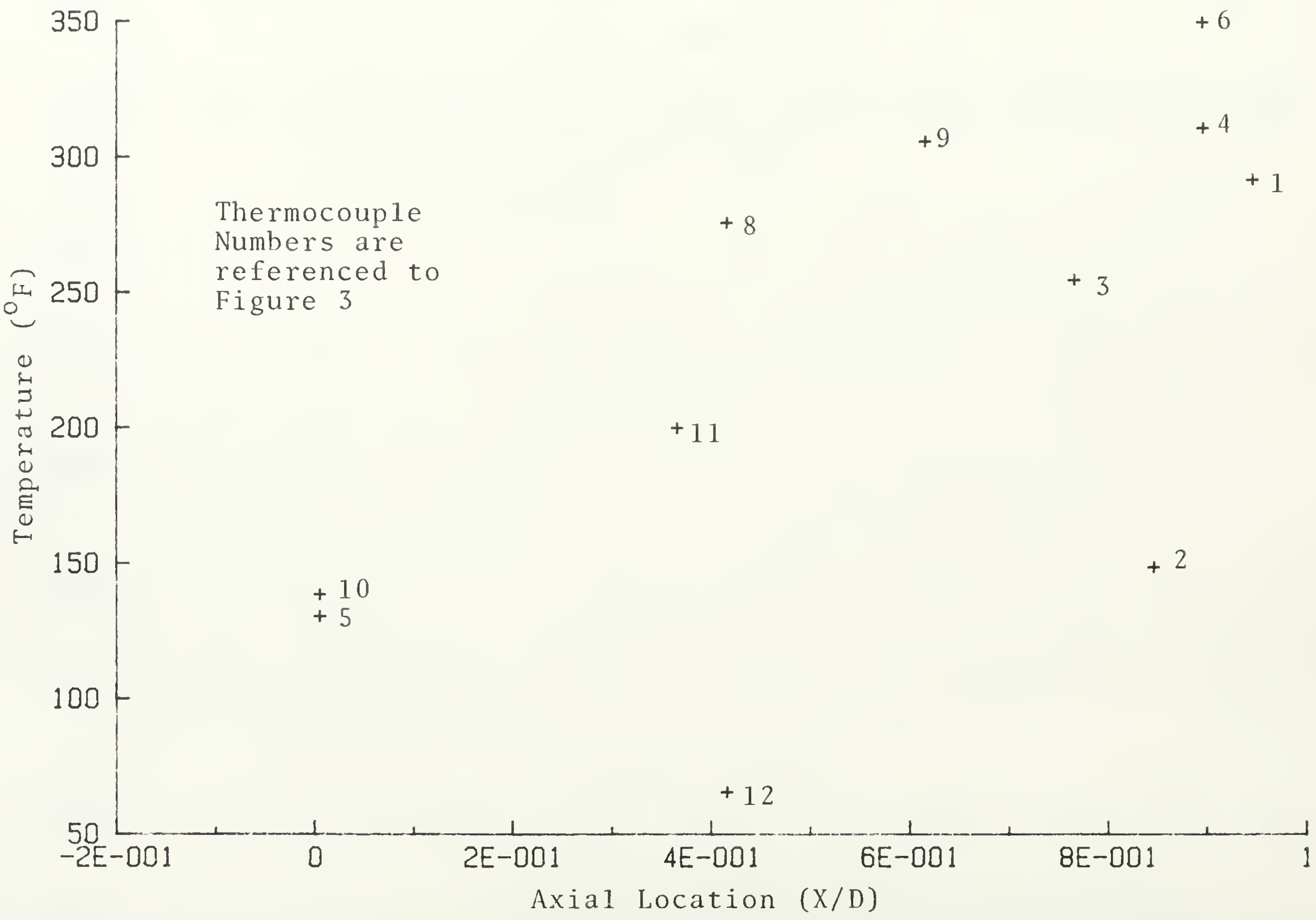


Figure 58. Mixing Stack Temperatures (950^{o}F), M=.06

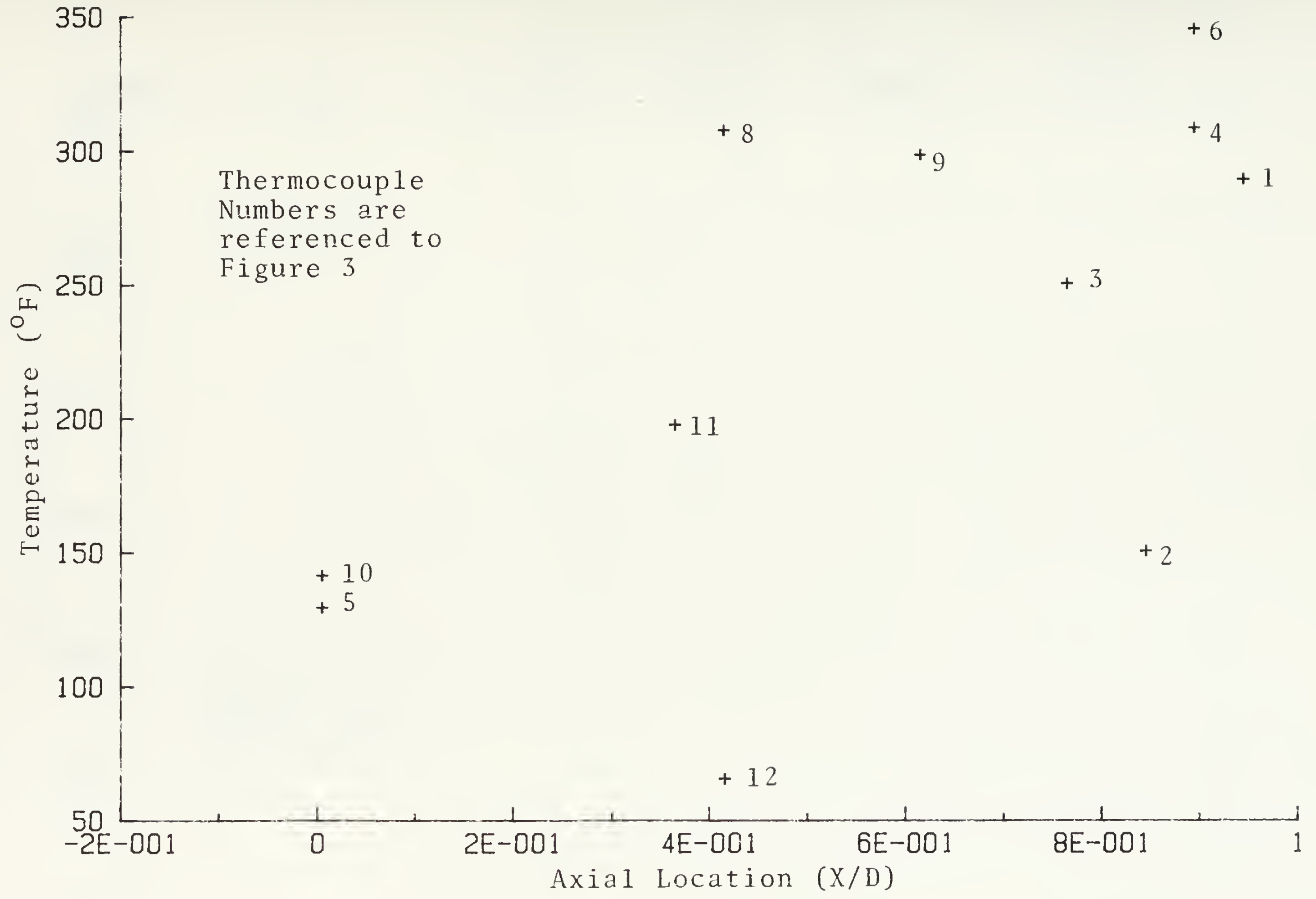


Figure 59. Mixing Stack Temperatures (950^{o}F), M=.053

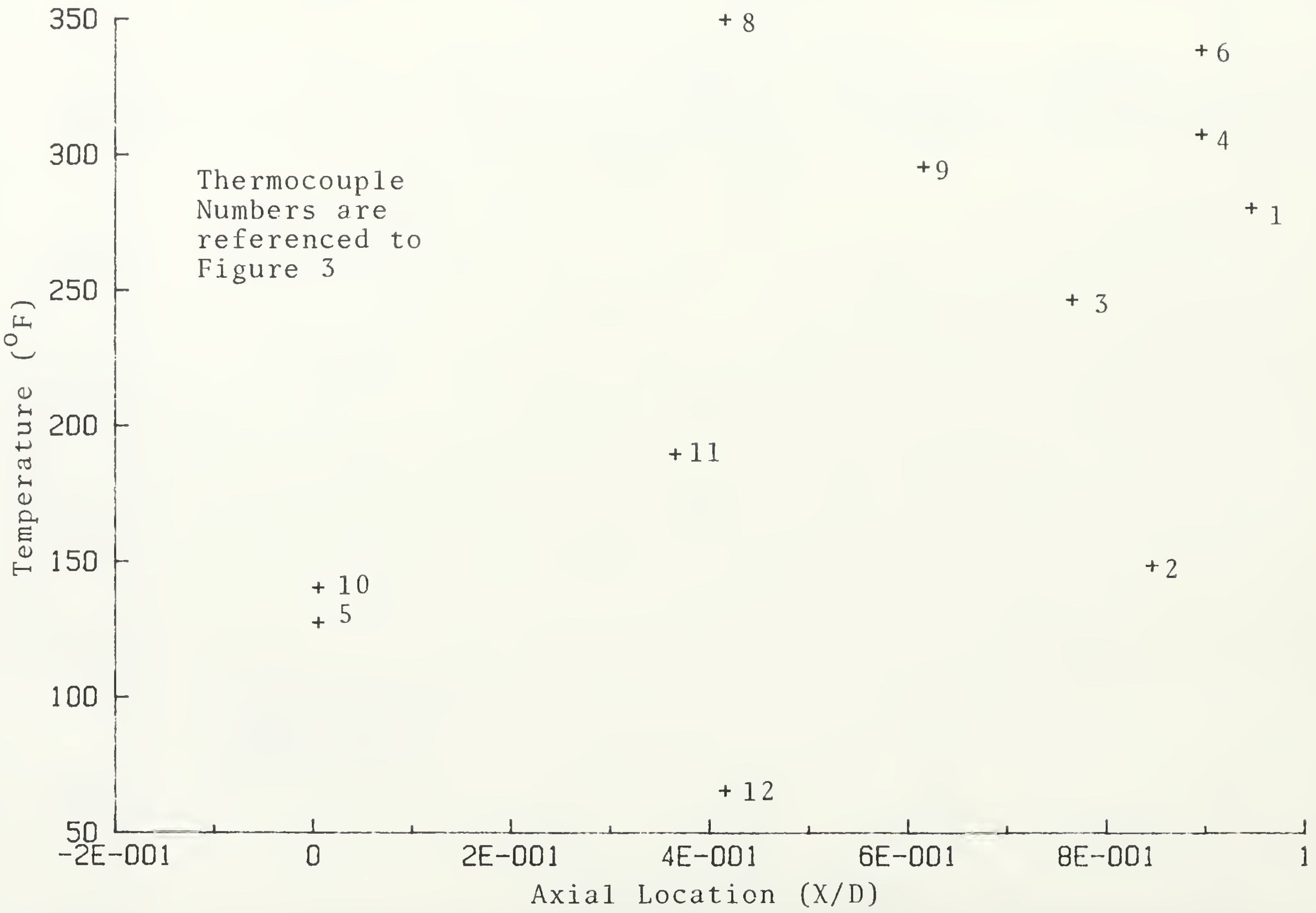


Figure 60. Mixing Stack Temperatures (950^oF), M=.047

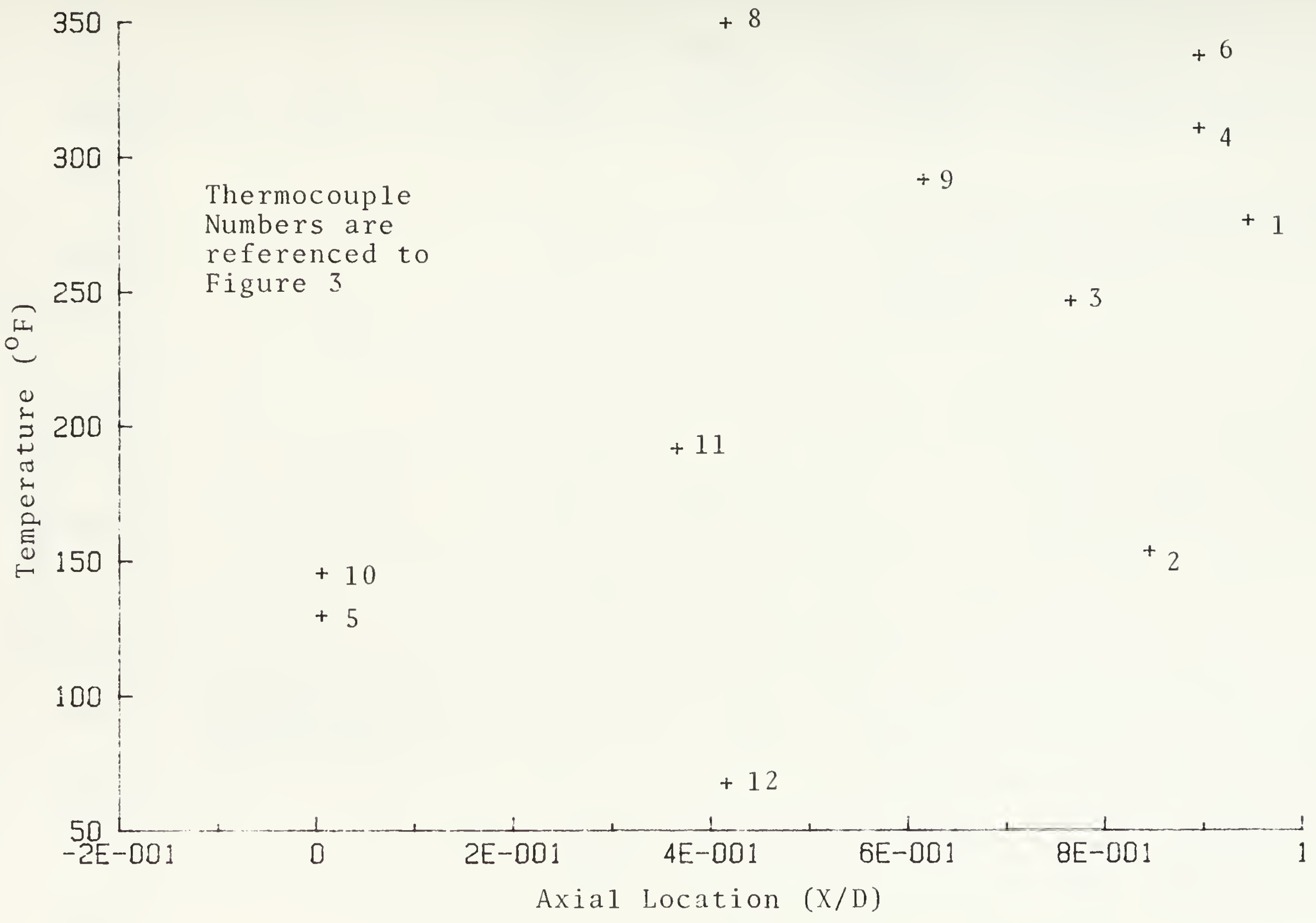


Figure 61. Mixing Stack Temperatures (950^oF), M=.036

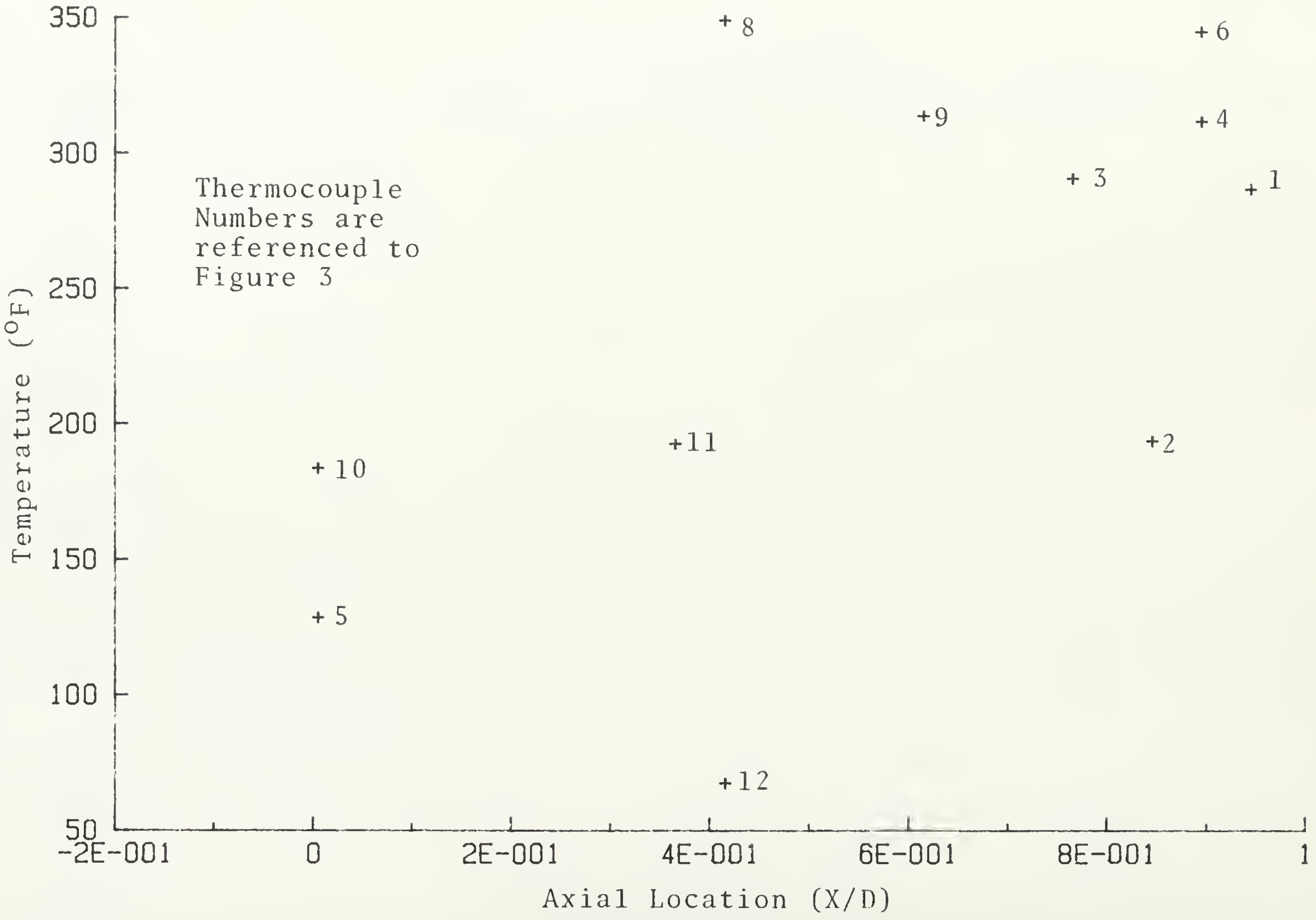


Figure 62. Mixing Stack Temperatures (950^oF), M=.024

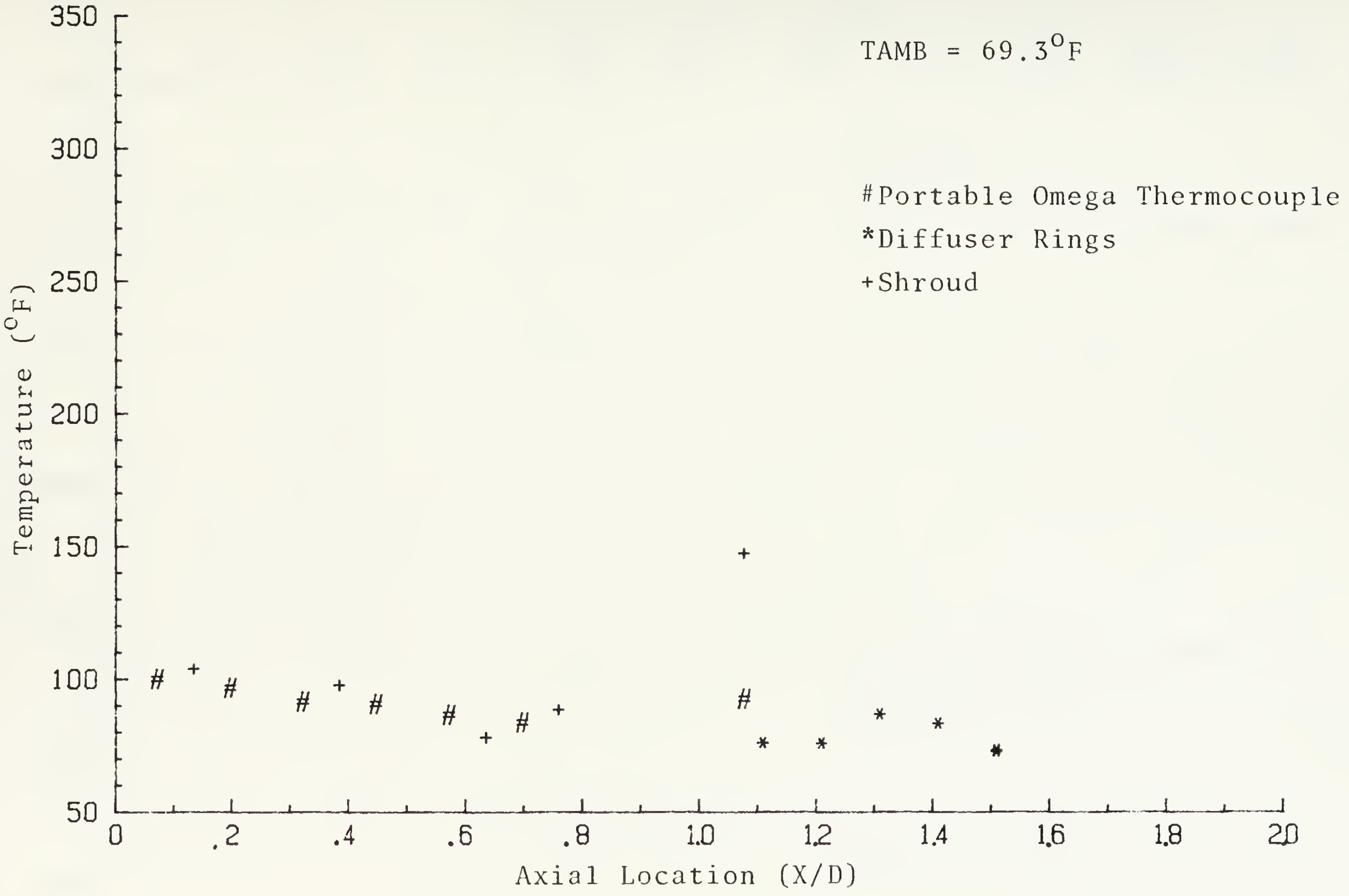


Figure 63. External Shroud and Diffuser Ring Temperatures (950°F), M=.06

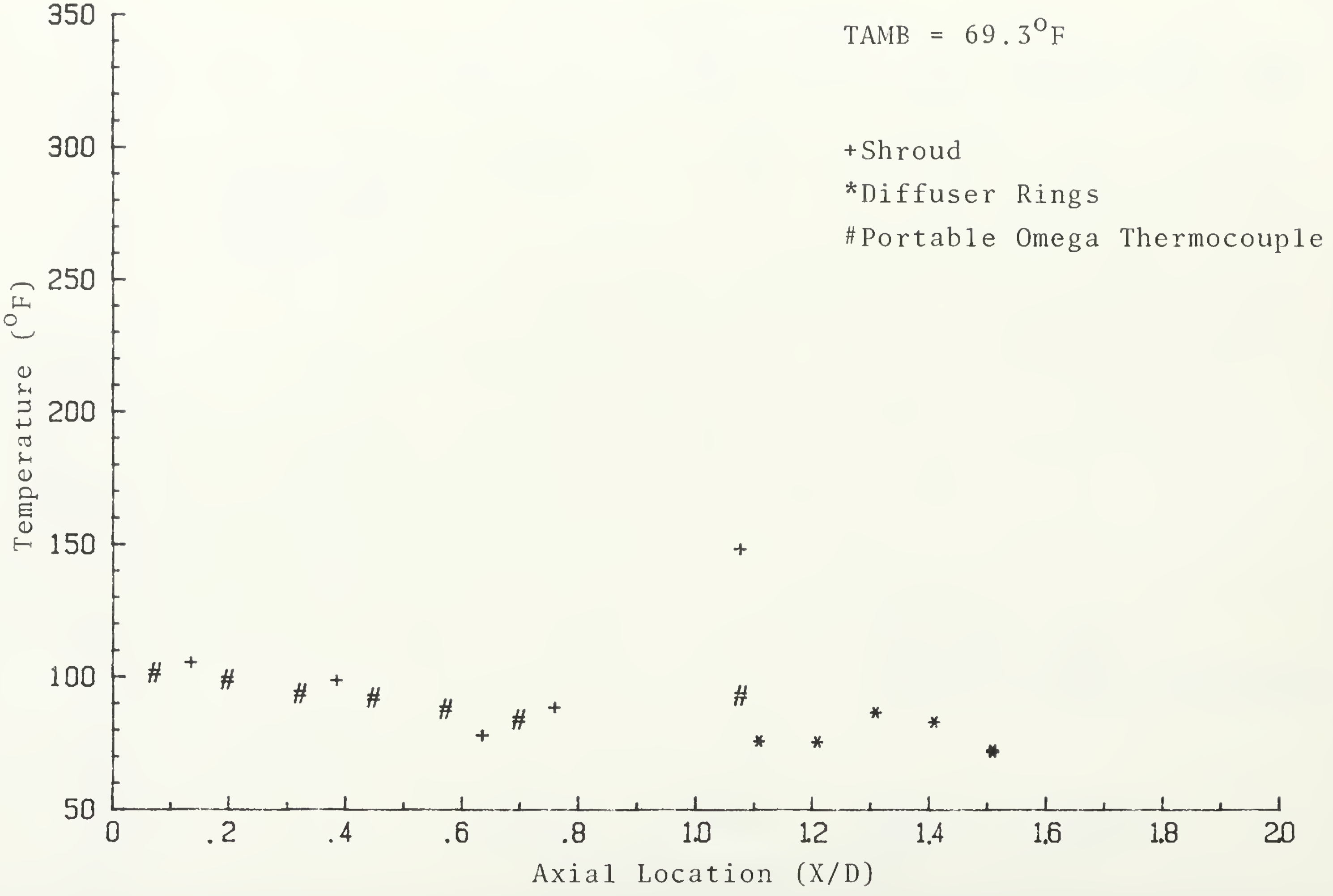


Figure 64. External Shroud and Diffuser Ring Temperatures (950°F), M=.053

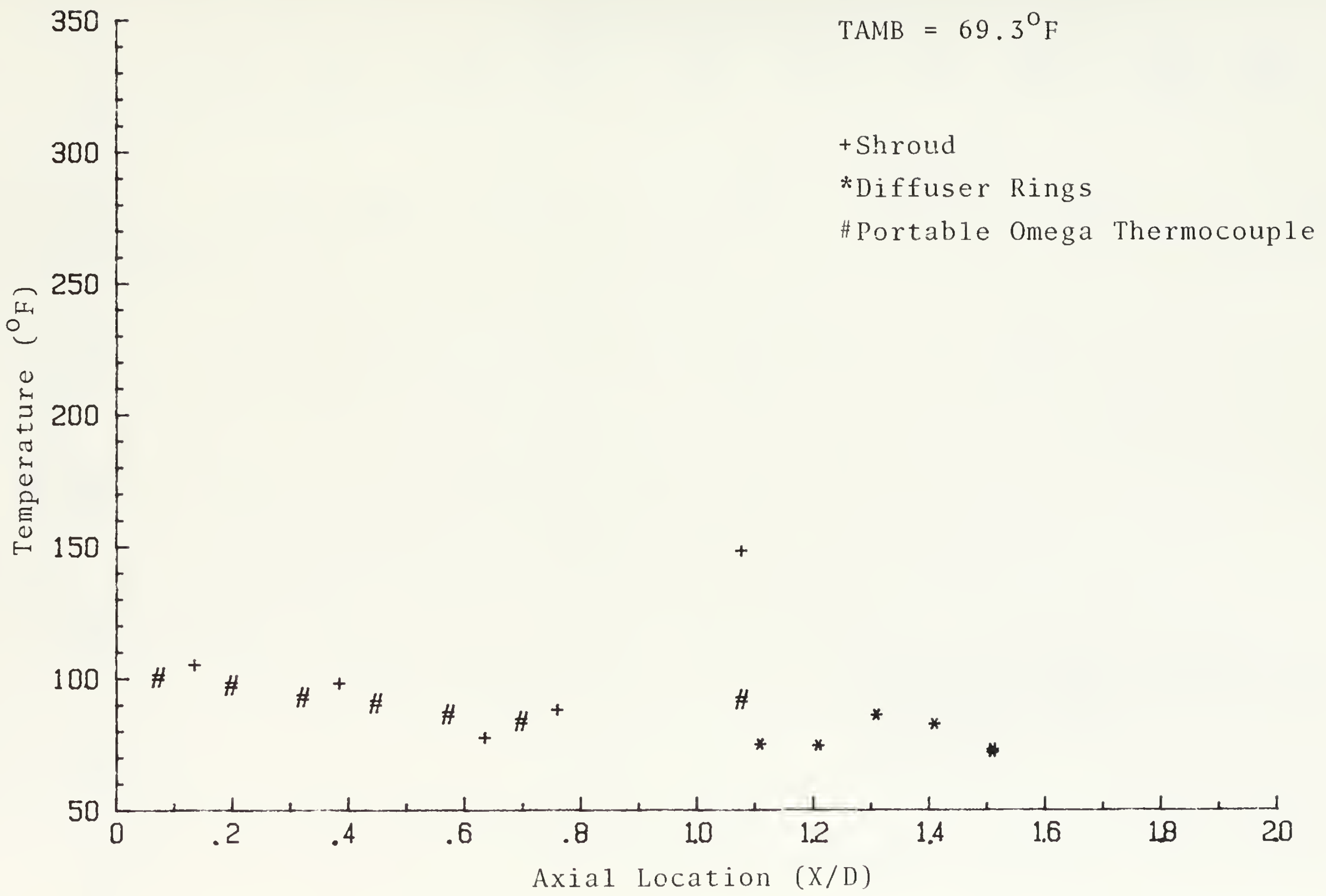


Figure 65. External Shroud and Diffuser Ring Temperatures (950°F), M=.047

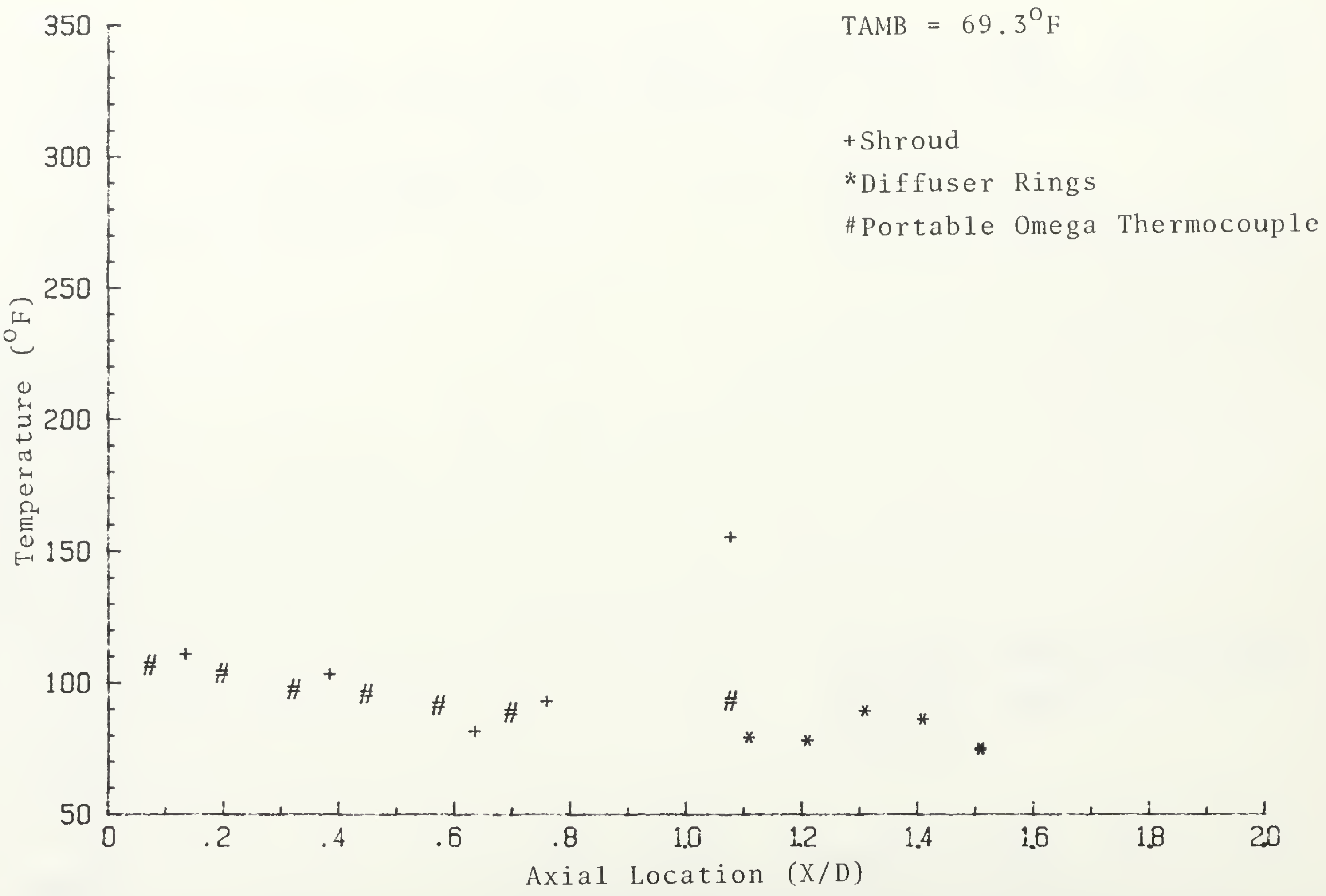


Figure 66. External Shroud and Diffuser Ring Temperatures (950°F), M=.036

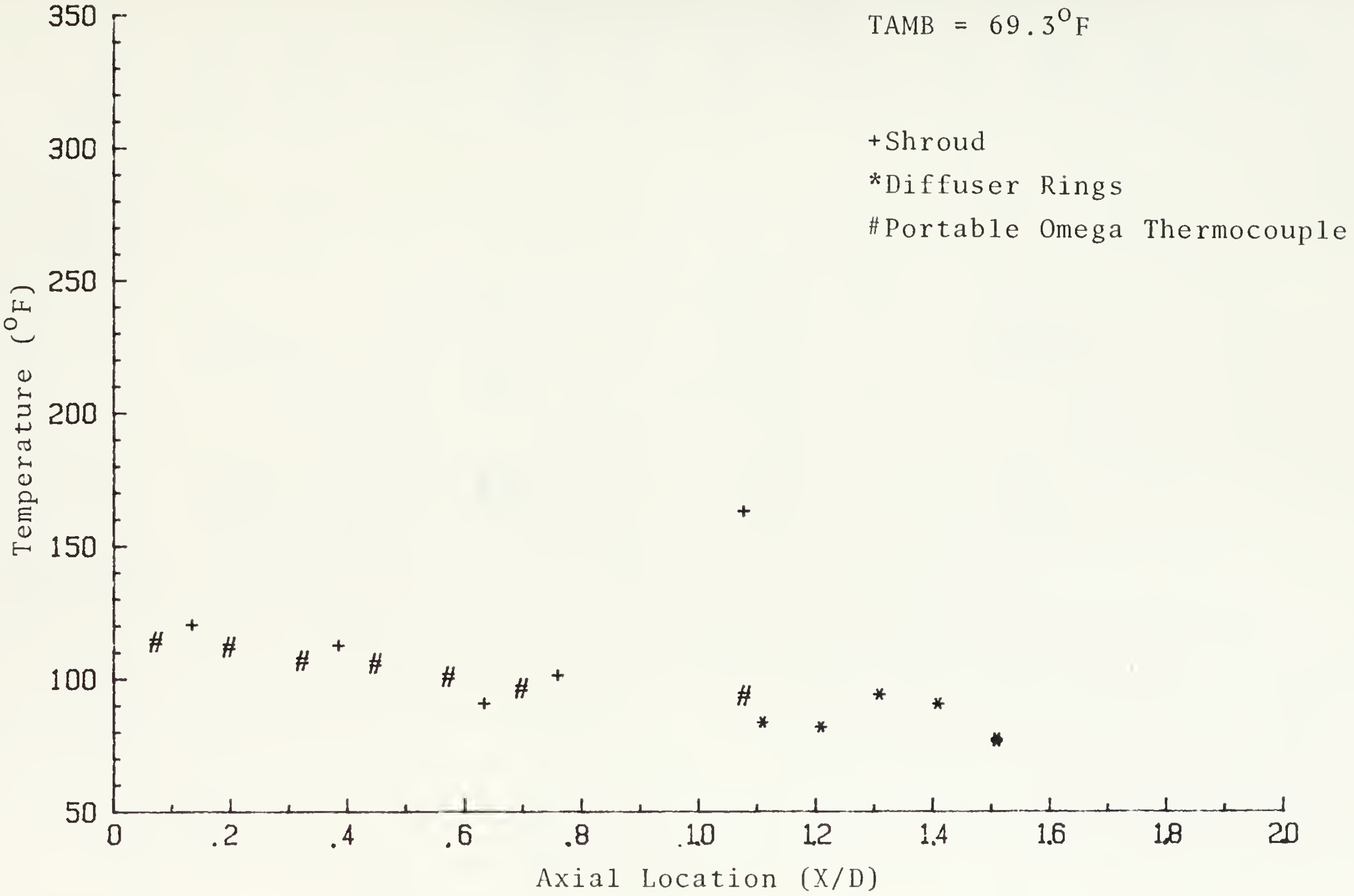


Figure 67. External Shroud and Diffuser Ring Temperatures (950^{o}F), M=.024

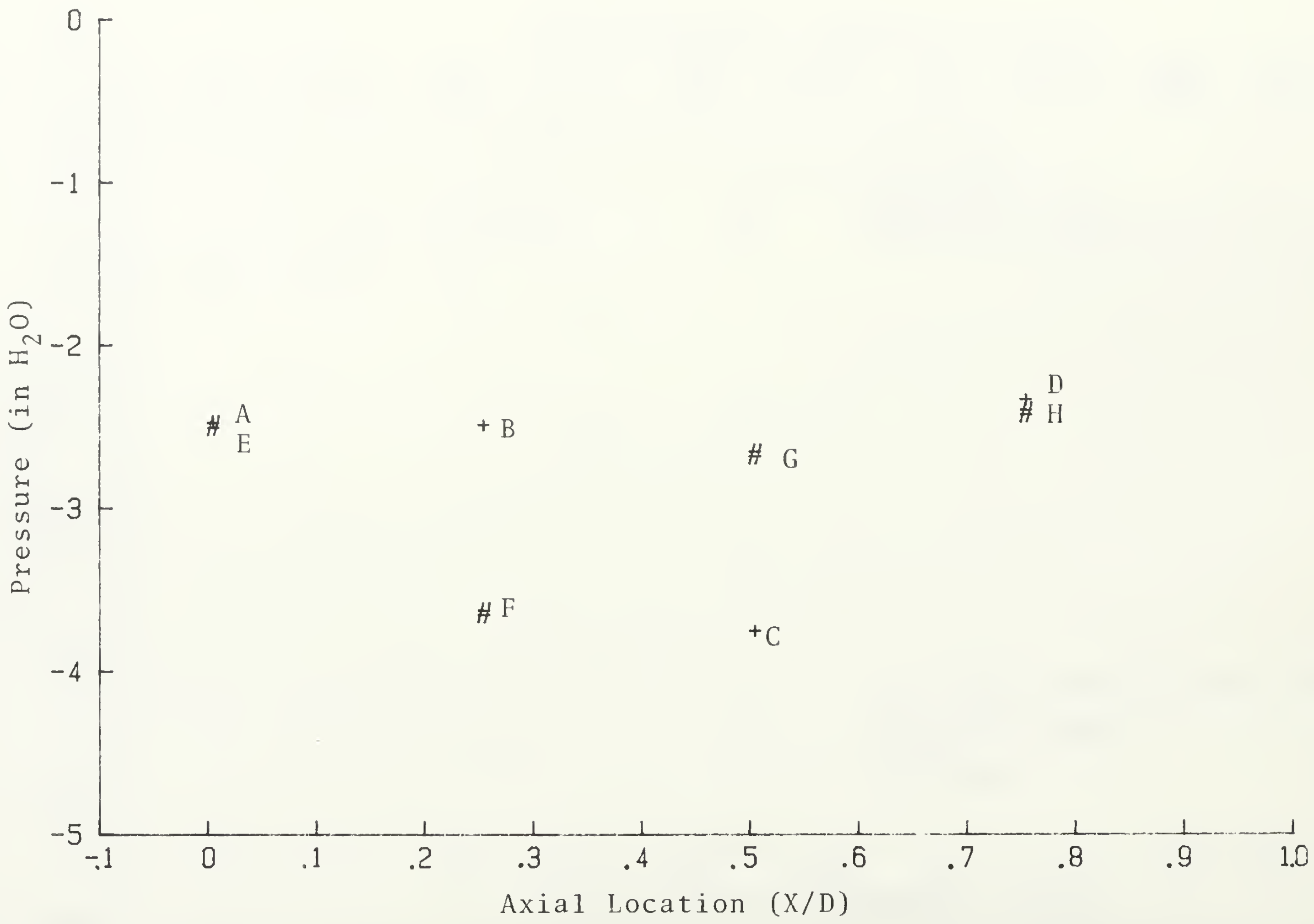


Figure 68. Mixing Stack Pressures (950^{O}F), M=.06

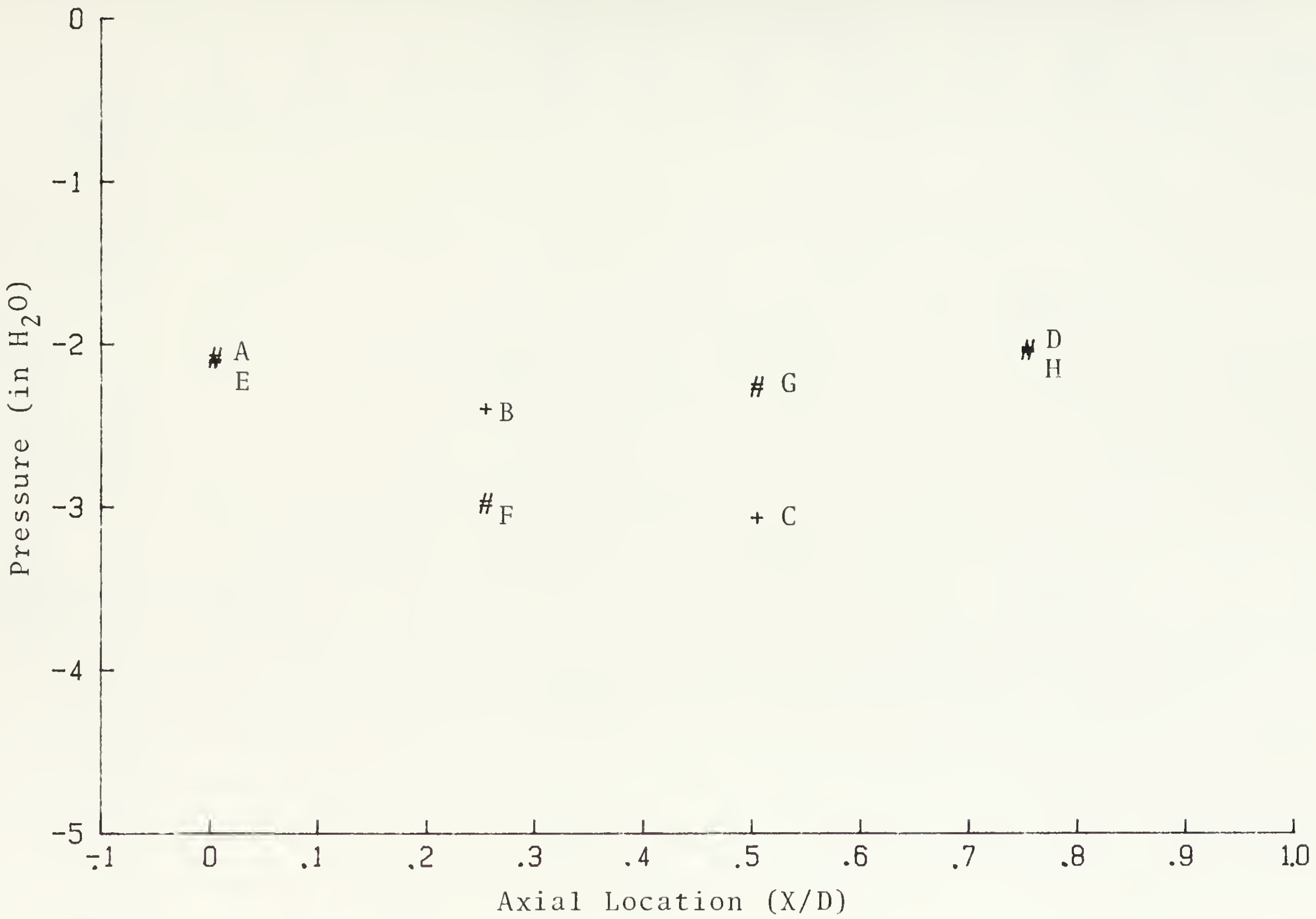


Figure 69. Mixing Stack Pressures (950°F), M=.053

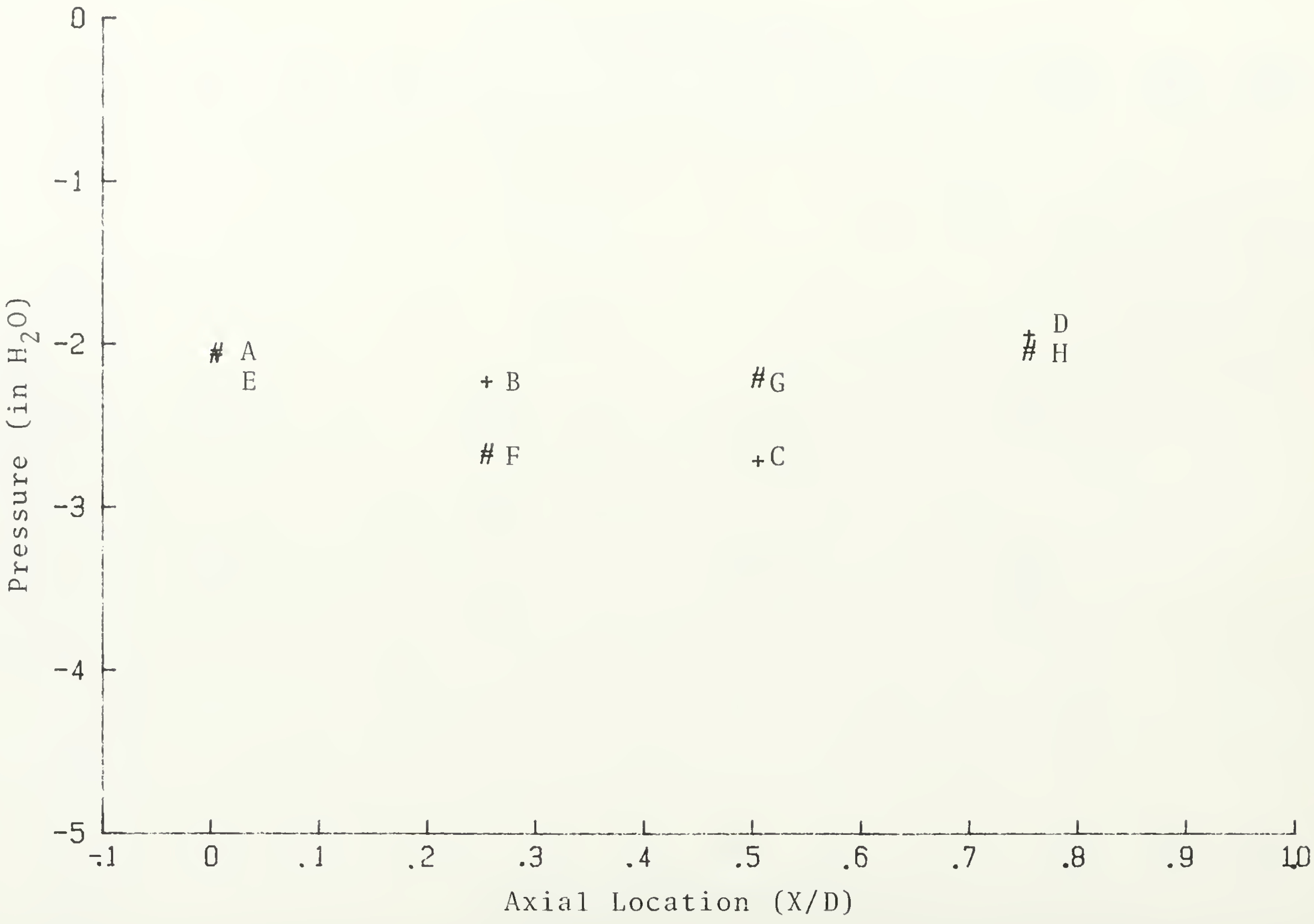


Figure 70. Mixing Stack Pressures ($950^{o}F$), M=.047

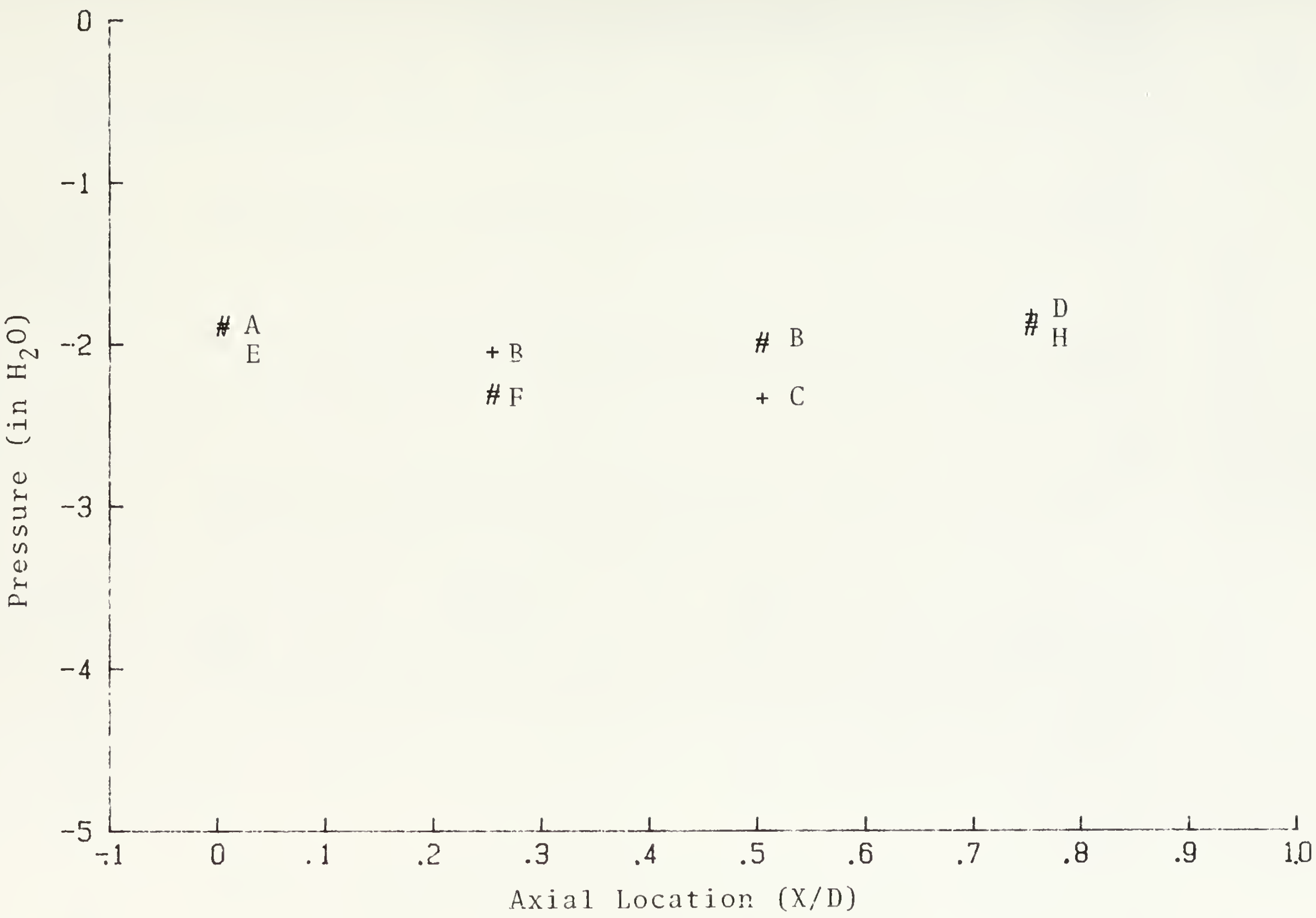


Figure 71. Mixing Stack Pressures (950^{o}F), M=.036

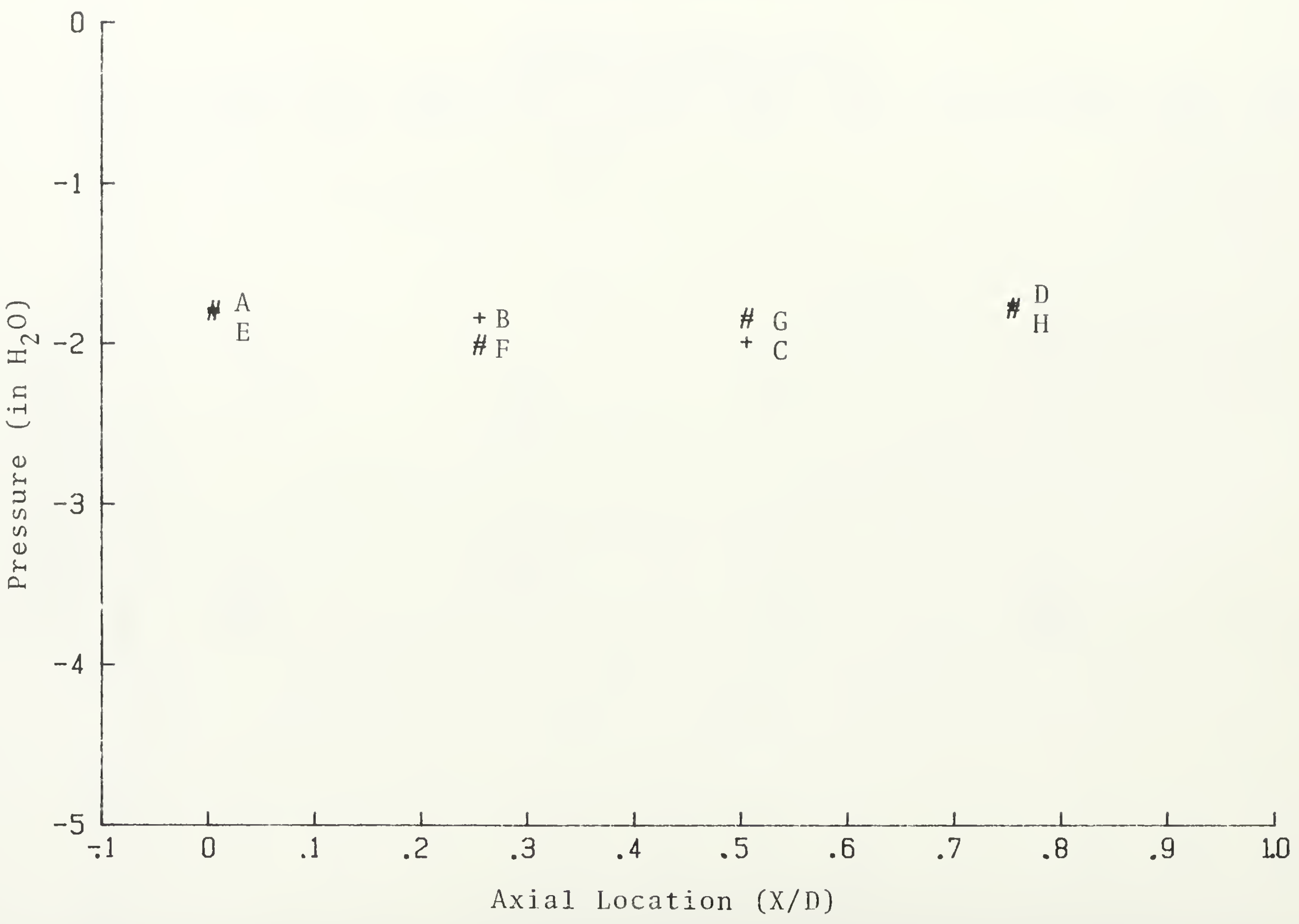


Figure 72. Mixing Stack Pressures (950^{o}F), M=.024

Table I

Rotameter Calibration Data

Rotameter Rdg	Container Wt. (lb) Empty	Full	Net	Elapsed Time (sec)	Flow Rate (lbm/sec)
8	1.68	1.76	0.08	120	.000667
10	1.69	1.85	0.16	120	.00133
15	1.68	1.99	0.31	120	.00258
20	1.69	2.20	0.51	120	.00418
25	1.68	2.45	0.77	120	.00642
30	1.69	2.73	1.04	120	.00867
35	1.71	3.08	1.37	120	.01142
40	1.70	3.32	1.62	120	.01350
35	1.71	3.08	1.37	120	.01142
30	1.69	2.77	1.08	120	.00900
25	1.68	2.47	0.79	120	.00658
20	1.71	2.21	0.50	120	.00417
15	1.68	1.99	0.31	120	.00258
10	1.71	1.87	0.61	120	.00133
5	1.69	1.77	0.08	120	.00667

Table II

Data Acquisition System Device Codes

DEVICE	HP IB CODE
HP 85 COMPUTER	0
HP 3497A SCANNER	9
HP 92190A DISK DRIVE	D700/D701
HP 7470A PLOTTER	5
DEC LS34 PRINTER	10

Table III

Scanivalve Calibration Data

DVM READING (volts)	MANOMETER READINGS (in H_2O)
.000523	9.55
.000384	7.40
.000097	3.05
-.000103	0.0
-.000037	1.0
.000286	5.9
.000497	9.1
-.000733	-9.6
-.000562	-7.0
-.000675	-8.7
-.000483	-5.75
-.000217	-1.7
-.000183	-1.2
-.000164	-0.9
-.000209	-1.55
-.000712	-9.25
.000128	3.4
-.000063	0.6
-.000035	1.05
-.000025	1.2
.000004	1.6
-.000007	1.45
-.000003	1.55
.000454	8.45

Table IV

Thermocouple Polynomial Coefficients

	TYPE K	TYPE T
a_0	0.226584602	0.100860910
a_1	24152.10900	25727.94369
a_2	67233.4248	-767345.8295
a_3	2210340.682	78025595.81
a_4	-860963914.9	-9247486589
a_5	4.83506 E10	6.97688 E11
a_6	-1.18452 E12	-2.66192 E13
a_7	1.3869 E13	3.90478 E14
a_8	-6.33708 E13	

Table V

HP 3497A Slot and Channel Assignments

SLOT 1 (Type T Thermocouples)

Channel	Assignment
0	Fuel Supply
1	Ambient
2	Inlet Air
3	Diffuser Ring 2
4	Diffuser Ring 3
5	Shroud (X/D = .625)
6	Diffuser Ring 6
7	Shroud (X/D = .750)
8	Diffuser Ring 6A
9	Diffuser Ring 6B
10	Diffuser Ring 1
11	Shroud (X/D = 1.068)
12	Shroud (X/D = .125)
13	Shroud (X/D = .375)
14	Diffuser Ring 4

SLOT 2 (Pressures)

Channel	Assignment
20	Atmospheric
21	Eductor Tap A
22	Eductor Tap E
23	Eductor Tap B
24	Eductor Tap F
25	Eductor Tap C
26	Uptake
27	Plenum (front)
28	Plenum (rear)
29	Eductor Tap D
30	Eductor Tap H
31	Eductor Tap G
32	Inlet
33	Entrance Nozzle Outlet
34	Entrance Nozzle Inlet
35	U Tube (near isolation valve)
36	U Tube (near burner)
37	Pitot (6.85" from primary nozzles)
38	Atmospheric

SLOT 3 (Type K Thermocouples)

Channel	Assignment
40	Exit Plane
41	Uptake
42	Burner
43	Nozzle Box at Second Burner
44	Plenum
45	Mixing Stack #10
46	Mixing Stack #2
47	Mixing Stack #11
48	Mixing Stack #4
49	Mixing Stack #9
50	Mixing Stack #5
51	Mixing Stack #3
52	Mixing Stack #6
53	Mixing Stack #1
54	Mixing Stack #7
55	Mixing Stack #8
56	Mixing Stack #12

Table VI

Model Design Characteristic Comparison

	Model A Mod	Model B
Mixing Stack Assembly L/D	1.5	1.5
Mixing Stack		
Inside Diameter	7.122	7.122
L/D	1.0	1.0
Rows of Cooling Slots	4	4
Shroud Start Position (X/D)	.15	.15
Diffuser		
Number of Rings	6	6
Ring Length (L/D)	.101	.3-.101
Half Angle	10	10
Standoff Distance (S/D)	0.5	0.5
Primary Nozzles		
Number	4	4
Type	Tilted-Angled (15/20)	Tilted-Angled (15/20)
A_m/A_p	2.5	2.5

Table VII

Air Mass Flow Calibration Data

PNH+B (in. Hg)	ΔPN (in. H_2O)	$\left[\frac{(PNH+B)\cdot \Delta PN}{TNHR}\right]^{0.5}$	$\dot{m}_a$ (lbm/sec)
31.15	2.0	0.319	0.554
31.15	2.0	0.316	0.555
31.15	2.0	0.319	0.591
32.85	4.0	0.459	0.833
32.65	4.0	0.462	0.838
33.85	4.0	0.435	0.852
34.75	6.0	0.582	1.026
35.05	6.0	0.579	1.051
38.65	6.0	0.606	1.126
38.55	8.0	0.706	1.295
39.15	8.0	0.705	1.300
47.65	8.0	0.774	1.477
51.55	8.5	0.827	1.595
47.95	10.0	0.875	1.634
48.75	10.0	0.877	1.643

Table VIII

Air Mass Flow vs Pressure Product Data

$\dot{m}_a$ (lbm/sec)	Pressure Product
0.554	0.319
0.555	0.316
0.591	0.319
0.833	0.459
0.838	0.462
0.852	0.435
1.026	0.582
1.051	0.579
1.126	0.606
1.295	0.706
1.300	0.705
1.477	0.774
1.595	0.827
1.634	0.875
1.643	0.877

Table IX

Pumping Coefficient Data, Model A Mod (175^{O}F)

HOT RIG PERFORMANCE
6 RING DIFFUSER
TUPT: 175

DATE: 14FEB84

DATA TAKEN BY R.W.WHITE

NUMBER OF PRIMARY NOZZLES: 4
PRIMARY NOZZLE DIAMETER: 2.25 INCHES
UPTAKE DIAMETER: 7.51 INCHES
AREA RATIO: 2.5
GAMMA: 1.399

MIXING STACK LENGTH: 7.122 INCHES
MIXING STACK DIAMETER: 7.122 INCHES
MIXING STACK L/D: 1.5
STANDOFF RATIO: .5
AMBIENT PRESSURE: 30.114 IN HG

NR	PNH IN HG	DELPN IN H2O	TNH DEG F	ROTA	TBURN DEG F	TUPT DEG F	TAMB DEG F	PUPT IN H2O	PPLN IN H2O	SEC AREA SQ IN	P*
1	2.47	9.04	171.5	0.0	168.0	171.0	54.2	4.33	2.40	0.000	.309
2	2.43	9.10	172.1	0.0	169.0	172.0	53.5	4.57	2.11	1.767	.269
3	2.47	8.42	172.3	0.0	169.0	172.0	54.0	4.89	1.85	3.534	.257
4	2.51	8.96	172.5	0.0	169.0	172.0	53.7	5.21	1.63	5.301	.211
5	2.55	9.36	172.8	0.0	169.0	172.0	53.7	5.74	1.31	8.443	.162
6	2.50	8.87	173.1	0.0	170.0	173.0	54.1	5.93	1.03	11.585	.135
7	2.63	9.19	173.5	0.0	170.0	173.0	54.0	6.20	.84	14.726	.105
8	2.62	8.84	173.7	0.0	170.0	173.0	53.9	6.67	.41	27.293	.054
9	2.66	8.63	174.2	0.0	170.0	174.0	54.6	6.85	.23	39.859	.031
10	2.64	8.84	174.5	0.0	171.0	174.0	54.7	6.94	.14	52.425	.018
11	2.63	8.43	175.0	0.0	171.0	174.0	54.8	6.88	.09	64.992	.013

NR	WPA LBM/S	WF LBM/S	WP LBM/S	WS LBM/S	W*	T*	P*/T*	W*T**.44	UP FT/S	UM FT/S	UU FT/S	UMACH
1	1.272	0.000	1.272	0.000	0.000	.815	.379	0.000	183.6	73.3	64.9	.053
2	1.275	0.000	1.275	.089	.069	.812	.332	.063	184.3	77.7	65.1	.053
3	1.226	0.000	1.226	.166	.135	.813	.316	.124	176.9	78.4	62.5	.051
4	1.267	0.000	1.267	.233	.184	.813	.259	.168	182.8	83.9	64.5	.052
5	1.296	0.000	1.296	.333	.257	.813	.199	.234	186.8	90.1	65.9	.054
6	1.259	0.000	1.259	.406	.322	.812	.167	.294	181.7	91.5	64.1	.052
7	1.285	0.000	1.285	.464	.361	.812	.130	.329	185.3	95.7	65.4	.053
8	1.259	0.000	1.259	.602	.479	.812	.066	.437	181.4	100.5	64.0	.052
9	1.243	0.000	1.243	.655	.527	.812	.038	.481	179.3	102.2	63.3	.051
10	1.258	0.000	1.258	.668	.530	.812	.022	.484	181.5	103.6	64.0	.052
11	1.227	0.000	1.227	.676	.551	.812	.016	.502	176.9	102.2	62.5	.051

Table X

Pumping Coefficient Data, Model A Mod (950^{o}F)

HOT RIG PERFORMANCE
6 RING DIFFUSER
TUPT: 950

DATE: 14FEB84

DATA TAKEN BY R.W.WHITE

NUMBER OF PRIMARY NOZZLES: 4
PRIMARY NOZZLE DIAMETER: 2.25 INCHES
UPTAKE DIAMETER: 7.51 INCHES
AREA RATIO: 2.5
GAMMA: 1.3556

MIXING STACK LENGTH: 7.122 INCHES
MIXING STACK DIAMETER: 7.122 INCHES
MIXING STACK L/D: 1.5
STANDOFF RATIO: .5
AMBIENT PRESSURE: 30.114 IN HG

NR	PNH IN HG	DELPN IN H2O	TNH DEG F	ROTA	TBURN DEG F	TUPT DEG F	TAMB DEG F	PUPT IN H2O	PPLN IN H2O	SEC AREA SQ IN	P*
1	3.99	3.99	181.6	43.0	1214.0	953.0	60.5	7.46	3.05	0.000	.175
2	4.03	3.57	181.3	43.0	1213.0	954.0	59.2	8.08	2.69	1.767	.172
3	4.02	3.60	181.3	43.0	1211.0	952.0	60.3	8.11	2.37	3.534	.151
4	4.02	3.37	181.4	43.0	1208.0	954.0	60.2	8.28	2.07	5.301	.141
5	4.05	3.74	181.6	43.0	1209.0	950.0	59.7	8.78	1.64	8.443	.101
6	4.01	3.63	181.1	43.0	1206.0	949.0	59.1	8.84	1.29	11.585	.082
7	4.01	3.22	181.2	43.0	1210.0	951.0	60.2	9.15	1.09	14.726	.079
8	4.05	3.39	181.2	43.0	1211.0	951.0	60.5	9.62	.55	27.293	.037
9	4.04	3.40	181.4	43.0	1211.0	952.0	62.2	9.54	.29	39.859	.020
10	4.08	3.80	181.3	43.0	1209.0	952.0	60.4	9.81	.18	52.425	.011
11	4.07	3.71	181.2	43.0	1211.0	952.0	60.3	9.74	.12	64.992	.008

NR	WPA LBM/S	WF LBM/S	WP LBM/S	WS LBM/S	W*	T*	P*/T*	W*T**.44	UP FT/S	UM FT/S	UU FT/S	UMACH
1	.843	.014	.857	0.000	0.000	.368	.474	0.000	277.5	110.8	97.1	.054
2	.795	.014	.809	.099	.123	.367	.469	.079	261.8	109.2	91.6	.051
3	.798	.014	.812	.186	.229	.368	.411	.148	262.4	113.6	91.8	.051
4	.771	.014	.785	.261	.332	.368	.383	.214	253.8	113.7	88.8	.049
5	.814	.014	.828	.371	.447	.368	.274	.288	266.8	124.1	93.4	.052
6	.802	.014	.816	.451	.553	.368	.223	.357	262.3	126.1	91.9	.051
7	.752	.014	.766	.528	.688	.369	.214	.444	246.6	123.4	86.4	.048
8	.773	.014	.787	.691	.878	.369	.101	.566	253.0	133.7	88.6	.049
9	.775	.014	.789	.732	.928	.370	.053	.599	253.5	135.9	88.9	.049
10	.822	.014	.836	.767	.917	.368	.030	.591	268.6	143.5	94.1	.052
11	.811	.014	.825	.776	.940	.368	.021	.606	265.2	142.5	93.0	.051

Table XI

Pumping Coefficient Data, Model B (175^{O}F), M=.06

HOT RIG PERFORMANCE
6 RING DIFFUSER
TUPT: 175

DATE: 6MAR84

DATA TAKEN BY R.W.WHITE

NUMBER OF PRIMARY NOZZLES: 4
PRIMARY NOZZLE DIAMETER: 2.25 INCHES
UPTAKE DIAMETER: 7.51 INCHES
AREA RATIO: 2.5
GAMMA: 1.3991

MIXING STACK LENGTH: 7.122 INCHES
MIXING STACK DIAMETER: 7.122 INCHES
MIXING STACK L/D: 1.5
STANDOFF RATIO: .5
AMBIENT PRESSURE: 29.926 IN HG

NR	PNH IN HG	DELPN IN H2O	TNH DEG F	ROTA	TBURN DEG F	TUPT DEG F	TAMB DEG F	PUPT IN H2O	PPLN IN H2O	SEC AREA SQ IN	P*
1	3.39	11.77	173.0	0.0	170.0	173.0	59.9	5.08	3.17	0.000	.303
2	3.34	11.56	173.3	0.0	171.0	173.0	60.1	5.44	2.75	1.767	.269
3	3.37	11.97	173.0	0.0	171.0	173.0	59.5	5.87	2.40	3.534	.226
4	3.42	11.21	173.3	0.0	171.0	173.0	60.2	6.03	2.05	5.301	.207
5	3.35	11.83	173.7	0.0	171.0	173.0	60.4	6.62	1.64	8.443	.157
6	3.37	10.88	173.7	0.0	171.0	173.0	59.6	6.97	1.31	11.585	.136
7	3.45	10.97	174.0	0.0	171.0	174.0	60.3	6.97	1.05	14.726	.108
8	3.50	11.56	173.9	0.0	171.0	174.0	60.6	7.46	.50	27.293	.049
9	3.45	11.67	174.0	0.0	171.0	174.0	59.6	7.64	.29	39.859	.028
10	3.46	11.16	174.1	0.0	171.0	174.0	59.7	7.81	.18	52.425	.018
11	3.41	11.18	174.3	0.0	171.0	174.0	60.0	7.98	.12	64.992	.012

NR	WPA LBM/S	WF LBM/S	WP LBM/S	WS LBM/S	W*	T*	P*/T*	W*T**.44	UP FT/S	UM FT/S	UU FT/S	UMACH
1	1.474	0.000	1.474	0.000	0.000	.821	.369	0.000	215.2	85.9	75.7	.061
2	1.459	0.000	1.459	.100	.069	.822	.327	.063	212.8	89.7	74.9	.061
3	1.487	0.000	1.487	.187	.126	.821	.275	.115	216.6	95.4	76.2	.062
4	1.438	0.000	1.438	.259	.180	.822	.252	.165	209.3	95.9	73.7	.060
5	1.477	0.000	1.477	.369	.250	.822	.191	.229	214.7	103.4	75.6	.061
6	1.414	0.000	1.414	.452	.320	.821	.166	.293	205.5	103.6	72.3	.059
7	1.421	0.000	1.421	.515	.362	.821	.132	.332	206.7	107.1	72.8	.059
8	1.462	0.000	1.462	.660	.451	.821	.060	.414	212.3	116.2	74.8	.061
9	1.468	0.000	1.468	.732	.499	.819	.034	.457	213.1	119.8	75.0	.061
10	1.435	0.000	1.435	.765	.533	.820	.023	.488	208.2	119.4	73.3	.059
11	1.435	0.000	1.435	.774	.539	.820	.015	.494	208.2	119.9	73.3	.059

Table XII

Pumping Coefficient Data, Model B (175^{O}F), M=.058

HOT RIG PERFORMANCE
6 RING DIFFUSER
TUPT: 175

DATE: 6MAR84

DATA TAKEN BY R.W.WHITE

NUMBER OF PRIMARY NOZZLES: 4
PRIMARY NOZZLE DIAMETER: 2.25 INCHES
UPTAKE DIAMETER: 7.5I INCHES
AREA RATIO: 2.5
GAMMA: I.3991

MIXING STACK LENGTH: 7.122 INCHES
MIXING STACK DIAMETER: 7.122 INCHES
MIXING STACK L/D: 1.5
STANDOFF RATIO: .5
AMBIENT PRESSURE: 29.926 IN HG

NR	PNH IN HG	DELPN IN H2O	TNH DEG F	ROTA	TBURN DEO F	TUPT DEG F	TAMB DEG F	PUPT IN H2O	PPLN IN H2O	SEC AREA SQ IN	P*
1	3.93	10.66	177.9	0.0	175.0	177.0	60.9	5.06	3.04	0.000	.316
2	4.00	10.31	178.1	0.0	174.0	177.0	61.8	5.39	2.63	1.767	.283
3	3.99	10.71	178.5	0.0	175.0	178.0	62.0	5.58	2.26	3.534	.234
4	4.03	11.15	178.1	0.0	175.0	178.0	62.0	5.93	1.99	5.30I	.197
5	4.00	10.37	178.2	0.0	175.0	178.0	61.2	6.37	1.58	8.443	.169
6	4.03	10.85	178.3	0.0	175.0	178.0	61.0	6.73	1.28	11.585	.130
7	3.96	10.44	178.2	0.0	175.0	178.0	60.7	7.08	1.03	14.726	.110
8	4.16	9.62	178.3	0.0	175.0	178.0	60.8	7.46	.49	27.293	.056
9	4.14	10.82	178.3	0.0	175.0	178.0	61.5	7.87	.27	39.859	.028
10	4.06	10.80	179.0	0.0	175.0	178.0	61.5	7.82	.17	52.425	.017
11	3.88	10.82	178.9	0.0	175.0	178.0	61.8	7.98	.14	64.992	.014

NR	WPA LBM/S	WF LBM/S	WP LBM/S	WS LBM/S	W*	T*	P*/T*	W*T**.44	UP FT/S	UM FT/S	UU FT/S	UMACH
1	1.407	0.000	1.407	0.000	0.000	.818	.386	0.000	206.6	82.5	72.7	.059
2	1.384	0.000	1.384	.098	.071	.819	.345	.065	203.0	85.7	71.5	.058
3	1.410	0.000	1.410	.181	.129	.818	.286	.118	207.1	91.4	72.9	.059
4	1.442	0.000	1.442	.255	.177	.818	.241	.162	211.5	96.6	74.5	.060
5	1.388	0.000	1.388	.362	.261	.817	.207	.239	203.4	98.5	71.6	.058
6	1.421	0.000	1.421	.447	.314	.816	.159	.287	208.1	104.4	72.3	.059
7	1.392	0.000	1.392	.511	.367	.816	.135	.336	203.7	105.7	71.7	.058
8	1.338	0.000	1.338	.649	.485	.816	.069	.444	195.5	109.0	68.9	.056
9	1.421	0.000	1.421	.711	.500	.817	.034	.458	207.6	116.8	73.1	.059
10	1.418	0.000	1.418	.731	.516	.817	.021	.472	207.1	117.5	72.9	.059
11	1.415	0.000	1.415	.819	.579	.818	.017	.530	206.6	121.5	72.7	.059

Table XIII

Pumping Coefficient Data, Model B (175°F), M=.048

HOT RIG PERFORMANCE
6 RING DIFFUSER
TUPT: 175

DATE: 6MAR84

DATA TAKEN BY R.W.WHITE

NUMBER OF PRIMARY NOZZLES: 4
PRIMARY NOZZLE DIAMETER: 2.25 INCHES
UPTAKE DIAMETER: 7.51 INCHES
AREA RATIO: 2.5
GAMMA: 1.3991

MIXING STACK LENGTH: 7.122 INCHES
MIXING STACK DIAMETER: 7.122 INCHES
MIXING STACK L/D: 1.5
STANDOFF RATIO: .5
AMBIENT PRESSURE: 29.926 IN HG

NR	PNH IN HG	DELPN IN H2O	TNH DEG F	ROTA	TBURN DEG F	TUPT DEG F	TAMB DEG F	PUPT IN H2O	PPLN IN H2O	SEC AREA SQ IN	P*
1	6.63	6.68	180.1	0.0	175.0	178.0	61.7	3.69	2.10	0.000	.328
2	6.74	6.49	180.1	0.0	175.0	178.0	60.8	3.88	1.84	1.767	.295
3	6.72	6.93	180.0	0.0	175.0	178.0	60.9	4.10	1.59	3.534	.240
4	6.81	5.83	180.0	0.0	175.0	178.0	62.3	4.32	1.38	5.301	.249
5	6.69	6.70	180.4	0.0	175.0	178.0	62.5	4.60	1.11	8.443	.174
6	6.65	6.36	180.0	0.0	175.0	178.0	62.4	4.89	.87	11.585	.143
7	6.80	7.38	180.2	0.0	175.0	178.0	62.6	5.00	.74	14.726	.105
8	6.76	6.81	180.0	0.0	175.0	178.0	62.0	5.29	.36	27.293	.056
9	6.84	6.67	180.1	0.0	175.0	178.0	61.4	5.52	.20	39.859	.031
10	6.74	6.59	180.3	0.0	175.0	178.0	62.3	5.59	.11	52.425	.017
11	6.75	7.02	180.2	0.0	175.0	178.0	61.1	5.59	.09	64.992	.014

NR	WPA LBM/S	WF LBM/S	WP LBM/S	WS LBM/S	W*	T*	P*/T*	W*T**.44	UP FT/S	UM FT/S	UU FT/S	UMACH
1	1.147	0.000	1.147	0.000	0.000	.818	.401	0.000	168.3	67.2	59.6	.048
2	1.131	0.000	1.131	.082	.072	.816	.362	.066	165.8	70.1	58.7	.047
3	1.170	0.000	1.170	.152	.130	.816	.294	.119	171.4	75.7	60.7	.049
4	1.071	0.000	1.071	.212	.198	.819	.304	.182	156.9	72.8	55.5	.045
5	1.149	0.000	1.149	.303	.264	.819	.212	.242	168.1	81.6	59.5	.048
6	1.118	0.000	1.118	.367	.329	.819	.175	.301	163.6	82.9	57.9	.047
7	1.210	0.000	1.210	.433	.358	.819	.128	.328	177.0	91.4	62.7	.051
8	1.160	0.000	1.160	.562	.484	.818	.068	.443	169.4	94.5	60.0	.048
9	1.149	0.000	1.149	.604	.526	.817	.038	.481	167.8	95.8	59.4	.048
10	1.140	0.000	1.140	.583	.511	.819	.021	.468	166.5	94.3	58.9	.048
11	1.178	0.000	1.178	.669	.568	.817	.017	.520	172.0	100.5	60.9	.049

Table XIV

Pumping Coefficient Data, Model B ($175^{o}F$), M=.036

HOT RIG PERFORMANCE
6 RING DIFFUSER
TUPT: 175

DATE: 6MAR84

DATA TAKEN BY R.W.WHITE

NUMBER OF PRIMARY NOZZLES: 4
PRIMARY NOZZLE DIAMETER: 2.25 INCHES
UPTAKE DIAMETER: 7.51 INCHES
AREA RATIO: 2.5
GAMMA: 1.3991

MIXING STACK LENGTH: 7.122 INCHES
MIXING STACK DIAMETER: 7.122 INCHES
MIXING STACK L/D: 1.5
STANDOFF RATIO: .5
AMBIENT PRESSURE: 29.926 IN HG

NR	PNH IN HG	DELPN IN H2O	TNH DEG F	ROTA	TBURN DEG F	TUPT DEG F	TAMB DEG F	PUPT IN H2O	PPLN IN H2O	SEC AREA SQ IN	P*
1	9.83	3.36	182.8	0.0	171.0	178.0	62.9	2.55	1.05	0.000	.312
2	9.87	3.24	182.8	0.0	171.0	178.0	63.7	2.69	.94	1.767	.292
3	9.89	2.73	182.6	0.0	171.0	178.0	63.3	2.80	.81	3.534	.298
4	9.89	2.49	182.6	0.0	171.0	178.0	62.9	2.90	.70	5.301	.286
5	9.80	3.42	182.8	0.0	171.0	178.0	63.9	3.02	.55	8.443	.161
6	9.84	3.48	183.3	0.0	171.0	178.0	64.4	3.16	.46	11.585	.131
7	9.86	2.89	183.3	0.0	173.0	179.0	64.3	3.22	.38	14.726	.133
8	9.79	3.90	183.3	0.0	173.0	179.0	64.9	3.36	.18	27.293	.047
9	9.80	3.46	183.3	0.0	173.0	179.0	66.1	3.51	.09	39.859	.026
10	9.82	2.76	183.2	0.0	172.0	178.0	65.3	3.47	.05	52.425	.017
11	9.77	3.78	183.1	0.0	172.0	178.0	64.2	3.48	.02	64.992	.004

NR	WPA LBM/S	WF LBM/S	WP LBM/S	WS LBM/S	W*	T*	P*/T*	W*T**.44	UP FT/S	UM FT/S	UU FT/S	UMACH
1	.833	0.000	.833	0.000	0.000	.819	.381	0.000	121.9	48.7	43.4	.035
2	.817	0.000	.817	.058	.071	.821	.356	.065	119.6	50.5	42.5	.034
3	.747	0.000	.747	.108	.144	.820	.364	.132	109.3	48.8	38.9	.031
4	.711	0.000	.711	.151	.212	.819	.349	.194	104.0	48.7	37.0	.030
5	.840	0.000	.840	.212	.253	.821	.196	.232	122.9	59.2	43.7	.035
6	.848	0.000	.848	.266	.314	.822	.160	.288	124.0	62.3	44.1	.036
7	.769	0.000	.769	.309	.402	.820	.162	.368	112.5	59.7	40.0	.032
8	.901	0.000	.901	.396	.440	.821	.057	.403	131.8	71.6	46.9	.038
9	.846	0.000	.846	.409	.483	.823	.032	.443	123.7	69.0	44.0	.036
10	.751	0.000	.751	.380	.506	.823	.020	.465	109.6	62.0	39.0	.032
11	.886	0.000	.886	.272	.307	.822	.005	.282	129.4	64.7	46.1	.037

Table XV

Pumping Coefficient Data, Model B (175^{O}F), M=.027

HOT RIG PERFORMANCE
6 RING DIFFUSER
TUPT: 175

DATE: 6MAR84

DATA TAKEN BY R.W.WHITE

NUMBER OF PRIMARY NOZZLES: 4
PRIMARY NOZZLE DIAMETER: 2.25 INCHES
UPTAKE DIAMETER: 7.51 INCHES
AREA RATIO: 2.5
GAMMA: 1.3991

MIXING STACK LENGTH: 7.122 INCHES
MIXING STACK DIAMETER: 7.122 INCHES
MIXING STACK L/D: 1.5
STANDOFF RATIO: .5
AMBIENT PRESSURE: 29.926 IN HG

NR	PNH IN HG	DELPN IN H2O	TNH DEG F	ROTA	TBURN DEG F	TUPT DEG F	TAMB DEG F	PUPT IN H2O	PPLN IN H2O	SEC AREA SQ IN	P*
1	11.53	2.51	180.1	0.0	167.0	175.0	64.1	1.46	.52	0.000	.203
2	11.59	1.35	179.8	0.0	167.0	175.0	63.6	1.63	.43	1.767	.324
3	11.62	1.72	179.4	0.0	164.0	174.0	62.3	1.60	.35	3.534	.205
4	11.54	1.82	179.6	0.0	163.0	173.0	63.3	1.69	.35	5.301	.194
5	11.57	2.37	179.2	0.0	163.0	173.0	63.2	1.67	.32	8.443	.133
6	11.50	2.16	179.3	0.0	162.0	173.0	64.8	1.79	.15	11.585	.071
7	11.46	2.01	179.6	0.0	162.0	173.0	64.2	1.70	.21	14.726	.107
8	11.52	1.69	179.0	0.0	162.0	173.0	62.9	1.85	.08	27.293	.046
9	11.56	.97	179.2	0.0	162.0	173.0	64.0	1.85	.05	39.859	.050
10	11.66	2.11	179.5	0.0	162.0	173.0	66.5	2.13	.05	52.425	.022
11	11.62	.65	179.7	0.0	163.0	173.0	64.9	2.14	.03	64.992	.053

NR	WPA LBM/S	WF LBM/S	WP LBM/S	WS LBM/S	W*	T*	P*/T*	W*T**.44	UP FT/S	UM FT/S	UU FT/S	UMACH
1	.731	0.000	.731	0.000	0.000	.825	.245	0.000	106.3	42.4	38.0	.031
2	.524	0.000	.524	.039	.075	.824	.393	.069	76.2	32.3	27.2	.022
3	.597	0.000	.597	.071	.119	.824	.249	.109	86.7	38.0	31.0	.025
4	.616	0.000	.616	.107	.173	.827	.234	.159	89.3	40.8	31.9	.026
5	.710	0.000	.710	.162	.229	.826	.161	.210	102.9	48.9	36.8	.030
6	.674	0.000	.674	.154	.228	.829	.085	.210	97.7	46.4	34.9	.028
7	.648	0.000	.648	.231	.356	.828	.129	.328	93.9	48.6	33.6	.027
8	.591	0.000	.591	.256	.433	.826	.055	.399	85.6	46.4	30.6	.025
9	.437	0.000	.437	.290	.662	.828	.061	.609	63.3	39.1	22.6	.018
10	.668	0.000	.668	.380	.569	.832	.026	.524	96.8	56.9	34.6	.028
11	.350	0.000	.350	.385	1.102	.829	.063	1.015	50.6	38.7	18.1	.015

Table XVI

Pumping Coefficient Data, Model B (950°F), M=.06

HOT RIG PERFORMANCE
6 RING DIFFUSER
TUPT: 950

DATE: 20MAR84

DATA TAKEN BY R.W.WHITE

NUMBER OF PRIMARY NOZZLES: 4
PRIMARY NOZZLE DIAMETER: 2.25 INCHES
UPTAKE DIAMETER: 7.51 INCHES
AREA RATIO: 2.5
GAMMA: 1.3556

MIXING STACK LENGTH: 7.122 INCHES
MIXING STACK DIAMETER: 7.122 INCHES
MIXING STACK L/D: 1.5
STANDOFF RATIO: .5
AMBIENT PRESSURE: 29.98 IN HG

NR	PNH IN HG	DELPN IN H2O	TNH DEG F	ROTA	TBURN DEG F	TUPT DEG F	TAMB DEG F	PUPT IN H2O	PPLN IN H2O	SEC AREA SQ IN	P*
1	3.97	5.23	178.6	39.0	1250.0	953.0	60.0	6.35	4.07	0.000	.175
2	4.01	4.80	178.8	39.0	1251.0	954.0	61.5	6.90	3.57	1.767	.168
3	3.99	5.29	178.9	39.0	1250.0	953.0	62.0	7.31	3.11	3.534	.133
4	4.01	4.68	178.3	39.0	1247.0	951.0	59.0	7.51	2.73	5.301	.132
5	4.05	5.03	178.3	39.0	1249.0	953.0	59.2	8.02	2.19	8.443	.098
6	4.09	5.27	178.7	39.0	1249.0	953.0	62.4	8.51	1.72	11.585	.074
7	4.03	4.60	178.5	39.0	1248.0	954.0	59.9	8.63	1.38	14.726	.068
8	4.08	5.19	178.8	39.0	1243.0	950.0	60.5	9.40	.65	27.293	.029
9	4.05	4.83	178.9	39.0	1246.0	954.0	61.8	9.47	.35	39.859	.016
10	4.12	5.00	179.1	39.0	1245.0	954.0	59.7	9.69	.23	52.425	.010
11	4.13	5.42	178.8	39.0	1247.0	955.0	59.2	9.72	.15	64.992	.006

NR	WPA LBM/S	WF LBM/S	WP LBM/S	WS LBM/S	W*	T*	P*/T*	W*T**.44	UP FT/S	UM FT/S	UU FT/S	UMACH
1	.971	.013	.984	0.000	0.000	.368	.476	0.000	320.7	128.1	112.3	.062
2	.929	.013	.942	.114	.121	.369	.456	.078	306.9	128.0	107.4	.059
3	.977	.013	.990	.213	.215	.369	.361	.139	321.9	138.7	112.7	.062
4	.917	.013	.929	.300	.323	.368	.360	.208	301.7	134.7	105.6	.058
5	.953	.013	.966	.427	.442	.367	.267	.285	313.4	145.4	109.7	.061
6	.977	.013	.990	.518	.523	.370	.200	.338	320.9	152.9	112.4	.062
7	.909	.013	.922	.592	.642	.368	.185	.413	298.8	147.4	104.7	.058
8	.970	.013	.982	.754	.767	.369	.077	.495	316.9	162.3	111.0	.061
9	.933	.013	.945	.804	.851	.369	.045	.549	305.6	160.3	107.1	.059
10	.950	.013	.963	.856	.889	.367	.028	.572	311.2	164.8	109.1	.060
11	.992	.013	1.005	.867	.862	.367	.017	.555	325.0	170.8	113.9	.063

Table XVII

Pumping Coefficient Data, Model B ($950^{O}F$), M=.06

HOT RIG PERFORMANCE
6 RING DIFFUSER
TUPT: 950

DATE: 20MAR84

DATA TAKEN BY R.W.WHITE

NUMBER OF PRIMARY NOZZLES: 4
PRIMARY NOZZLE DIAMETER: 2.25 INCHES
UPTAKE DIAMETER: 7.51 INCHES
AREA RATIO: 2.5
GAMMA: 1.3556

MIXING STACK LENGTH: 7.122 INCHES
MIXING STACK DIAMETER: 7.122 INCHES
MIXING STACK L/D: 1.5
STANDOFF RATIO: .5
AMBIENT PRESSURE: 29.98 IN HG

NR	PNH IN HG	DELPN IN H2O	TNH DEG F	ROTA	TBURN DEG F	TUPT DEG F	TAMB DEG F	PUPT IN H2O	PPLN IN H2O	SEC AREA SQ IN	P*
1	3.97	5.03	178.6	39.0	1250.0	953.0	60.0	6.35	4.07	0.000	.182
2	4.01	5.03	178.8	39.0	1251.0	954.0	61.5	6.90	3.57	1.767	.160
3	3.99	5.03	178.9	39.0	1250.0	953.0	62.0	7.31	3.11	3.534	.140
4	4.01	5.03	178.3	39.0	1247.0	951.0	59.0	7.51	2.73	5.301	.123
5	4.05	5.03	178.3	39.0	1249.0	953.0	59.2	8.02	2.19	8.443	.098
6	4.09	5.03	178.7	39.0	1249.0	953.0	62.4	8.51	1.72	11.585	.077
7	4.03	5.03	178.5	39.0	1248.0	954.0	59.9	8.63	1.38	14.726	.062
8	4.08	5.03	178.8	39.0	1243.0	950.0	60.5	9.40	.65	27.293	.030
9	4.05	5.03	178.9	39.0	1246.0	954.0	61.8	9.47	.35	39.859	.016
10	4.12	5.03	179.1	39.0	1245.0	954.0	59.7	9.69	.23	52.425	.010
11	4.13	5.03	178.8	39.0	1247.0	955.0	59.2	9.72	.15	64.992	.007

NR	WPA LBM/S	WF LBM/S	WP LBM/S	WS LBM/S	W*	T*	P*/T*	W*T**.44	UP FT/S	UM FT/S	UU FT/S	UMACH
1	.952	.013	.964	0.000	0.000	.368	.496	0.000	314.5	125.6	110.1	.061
2	.952	.013	.965	.114	.118	.369	.434	.076	314.4	131.0	110.0	.061
3	.952	.013	.964	.213	.221	.369	.380	.142	313.7	135.5	109.8	.061
4	.953	.013	.965	.300	.311	.368	.334	.200	313.2	139.3	109.7	.061
5	.953	.013	.966	.427	.442	.367	.267	.285	313.5	145.5	109.8	.061
6	.953	.013	.966	.518	.536	.370	.209	.346	313.2	149.8	109.7	.060
7	.953	.013	.965	.592	.613	.368	.169	.395	312.9	153.1	109.6	.060
8	.953	.013	.966	.754	.780	.369	.080	.503	311.6	160.2	109.2	.060
9	.953	.013	.965	.804	.833	.369	.043	.537	312.1	162.9	109.4	.060
10	.954	.013	.966	.856	.886	.367	.028	.570	312.3	165.2	109.5	.060
11	.954	.013	.967	.867	.897	.367	.019	.577	312.6	165.8	109.6	.060

Table XVIII

Pumping Coefficient Data, Model B ($950^{o}F$), M=.053

HOT RIG PERFORMANCE
6 RING DIFFUSER
TUPT: 950

DATE: 9MAR84

DATA TAKEN BY R.W.WHITE

NUMBER OF PRIMARY NOZZLES: 4
PRIMARY NOZZLE DIAMETER: 2.25 INCHES
UPTAKE DIAMETER: 7.51 INCHES
AREA RATIO: 2.5
GAMMA: 1.3556

MIXING STACK LENGTH: 7.122 INCHES
MIXING STACK DIAMETER: 7.122 INCHES
MIXING STACK L/D: 1.5
STANDOFF RATIO: .5
AMBIENT PRESSURE: 30.126 IN HG

NR	PNH IN HG	DELPN IN H2O	TNH DEG F	ROTA	TBURN DEG F	TUPT DEG F	TAMB DEG F	PUPT IN H2O	PPLN IN H2O	SEC AREA SQ IN	P*
1	3.91	4.09	178.6	35.0	1239.0	950.0	59.5	6.35	2.99	0.000	.168
2	3.93	4.27	178.4	35.0	1236.0	951.0	59.3	6.72	2.67	1.767	.143
3	3.90	4.27	178.3	35.0	1236.0	950.0	58.8	7.13	2.32	3.534	.125
4	3.96	3.60	178.1	35.0	1240.0	952.0	59.8	7.44	2.04	5.301	.130
5	3.94	3.68	178.0	35.0	1238.0	949.0	59.4	7.92	1.59	8.443	.101
6	4.03	3.65	178.2	35.0	1238.0	951.0	59.8	7.82	1.31	11.585	.083
7	3.98	4.10	178.2	35.0	1240.0	952.0	58.8	8.31	1.03	14.726	.058
8	4.02	3.90	178.6	35.0	1241.0	953.0	60.4	8.51	.50	27.293	.030
9	3.99	3.74	178.6	35.0	1242.0	952.0	61.0	8.83	.27	39.859	.017
10	4.06	3.46	178.3	35.0	1240.0	951.0	60.7	9.09	.17	52.425	.011
11	4.02	4.57	178.7	35.0	1242.0	952.0	61.8	8.93	.11	64.992	.005

NR	WPA LBM/S	WF LBM/S	WP LBM/S	WS LBM/S	W*	T*	P*/T*	W*T**.44	UP FT/S	UM FT/S	UU FT/S	UMACH
1	.854	.011	.865	0.000	0.000	.368	.457	0.000	279.4	111.5	98.1	.054
2	.874	.011	.885	.099	.112	.368	.390	.072	285.9	118.8	100.3	.055
3	.874	.011	.885	.185	.209	.368	.340	.134	285.4	122.7	100.1	.055
4	.800	.011	.811	.259	.320	.368	.354	.206	261.5	116.7	91.8	.051
5	.808	.011	.819	.366	.446	.368	.273	.288	263.5	122.5	92.4	.051
6	.806	.011	.817	.454	.556	.368	.225	.358	262.8	126.4	92.3	.051
7	.857	.011	.868	.513	.592	.367	.157	.381	279.3	135.7	98.0	.054
8	.835	.011	.846	.662	.782	.368	.080	.504	272.2	139.9	95.6	.053
9	.816	.011	.827	.714	.863	.369	.046	.557	265.6	139.8	93.3	.051
10	.784	.011	.795	.734	.923	.369	.030	.595	255.3	136.6	89.6	.049
11	.908	.011	.919	.725	.789	.369	.014	.509	295.0	152.1	103.6	.057

Table XIX

Pumping Coefficient Data, Model B (950^{o}F), M=.053

HOT RIG PERFORMANCE
6 RING DIFFUSER
TUPT: 950

DATE: 9MAR84

DATA TAKEN BY R.W.WHITE

NUMBER OF PRIMARY NOZZLES: 4
PRIMARY NOZZLE DIAMETER: 2.25 INCHES
UPTAKE DIAMETER: 7.51 INCHES
AREA RATIO: 2.5
GAMMA: 1.3556

MIXING STACK LENGTH: 7.122 INCHES
MIXING STACK DIAMETER: 7.122 INCHES
MIXING STACK L/D: 1.5
STANDOFF RATIO: .5
AMBIENT PRESSURE: 30.126 IN HG

NR	PNH IN HG	DELPN IN H2O	TNH DEG F	ROTA	TBURN DEG F	TUPT DEG F	TAMB DEG F	PUPT IN H2O	PPLN IN H2O	SEC AREA SQ IN	P*
1	3.91	3.94	178.6	35.0	1239.0	950.0	59.5	6.35	2.99	0.000	.175
2	3.93	3.94	178.4	35.0	1236.0	951.0	59.3	6.72	2.67	1.767	.156
3	3.90	3.94	178.3	35.0	1236.0	950.0	58.8	7.13	2.32	3.534	.136
4	3.96	3.94	178.1	35.0	1240.0	952.0	59.8	7.44	2.04	5.301	.119
5	3.94	3.94	178.0	35.0	1238.0	949.0	59.4	7.92	1.59	8.443	.094
6	4.03	3.94	178.2	35.0	1238.0	951.0	59.8	7.82	1.31	11.585	.076
7	3.98	3.94	178.2	35.0	1240.0	952.0	58.8	8.31	1.03	14.726	.060
8	4.02	3.94	178.6	35.0	1241.0	953.0	60.4	8.51	.50	27.293	.029
9	3.99	3.94	178.6	35.0	1242.0	952.0	61.0	8.83	.27	39.859	.016
10	4.06	3.94	178.3	35.0	1240.0	951.0	60.7	9.09	.17	52.425	.010
11	4.02	3.94	178.7	35.0	1242.0	952.0	61.8	8.93	.11	64.992	.006

NR	WPA LBM/S	WF LBM/S	WP LBM/S	WS LBM/S	W*	T*	P*/T*	W*T**.44	UP FT/S	UM FT/S	UU FT/S	UMACH
1	.838	.011	.849	0.000	0.000	.368	.475	0.000	274.1	109.4	96.2	.053
2	.838	.011	.849	.099	.117	.368	.424	.075	274.1	114.1	96.2	.053
3	.838	.011	.849	.185	.218	.368	.369	.140	273.6	118.0	96.0	.053
4	.839	.011	.850	.259	.305	.368	.323	.197	274.1	121.7	96.2	.053
5	.838	.011	.849	.366	.430	.368	.254	.277	273.2	126.4	95.8	.053
6	.839	.011	.850	.454	.534	.368	.207	.344	273.7	130.7	96.1	.053
7	.839	.011	.850	.513	.604	.367	.164	.389	273.5	133.4	96.0	.053
8	.839	.011	.850	.662	.779	.368	.080	.502	273.4	140.4	96.0	.053
9	.839	.011	.850	.714	.840	.369	.044	.541	272.9	142.7	95.9	.053
10	.840	.011	.851	.734	.863	.369	.027	.556	273.0	143.7	95.9	.053
11	.839	.011	.850	.725	.853	.369	.017	.550	272.9	143.3	95.9	.053

Table XX

Pumping Coefficient Data, Model B ($950^{O}F$), M=.047

HOT RIG PERFORMANCE
6 RING DIFFUSER
TUPT: 950

DATE: 20MAR84

DATA TAKEN BY R.W.WHITE

NUMBER OF PRIMARY NOZZLES: 4
PRIMARY NOZZLE DIAMETER: 2.25 INCHES
UPTAKE DIAMETER: 7.51 INCHES
AREA RATIO: 2.5
GAMMA: 1.3556

MIXING STACK LENGTH: 7.122 INCHES
MIXING STACK DIAMETER: 7.122 INCHES
MIXING STACK L/D: 1.5
STANDOFF RATIO: .5
AMBIENT PRESSURE: 29.796 IN HG

NR	PNH IN HG	DELPN IN H2O	TNH DEG F	ROTA	TBURN DEG F	TUPT DEG F	TAMB DEG F	PUPT IN H2O	PPLN IN H2O	SEC AREA SQ IN	P*
1	9.02	3.07	175.9	34.0	1267.0	950.0	64.3	5.09	2.84	0.000	.187
2	8.99	3.28	176.2	34.0	1265.0	951.0	65.4	5.38	2.49	1.767	.153
3	8.97	3.01	176.0	34.0	1264.0	952.0	64.4	5.45	2.19	3.534	.147
4	8.94	2.58	176.3	34.0	1262.0	953.0	63.8	5.85	1.88	5.301	.149
5	9.00	2.08	176.2	34.0	1260.0	953.0	64.4	6.20	1.50	8.443	.149
6	9.00	2.69	176.3	34.0	1266.0	953.0	62.4	6.44	1.22	11.585	.092
7	9.03	2.76	176.3	34.0	1271.0	954.0	64.4	6.50	.97	14.726	.071
8	9.04	2.81	176.3	34.0	1271.0	954.0	62.4	7.17	.47	27.293	.034
9	8.93	2.07	176.3	34.0	1273.0	954.0	62.4	7.29	.27	39.859	.027
10	9.04	2.43	176.1	34.0	1268.0	952.0	63.1	7.35	.15	52.425	.013
11	9.06	2.49	176.2	34.0	1264.0	954.0	62.5	7.34	.11	64.992	.009

NR	WPA LBM/S	WF LBM/S	WP LBM/S	WS LBM/S	W*	T*	P*/T*	W*T**.44	UP FT/S	UM FT/S	UU FT/S	UMACH
1	.789	.011	.799	0.000	0.000	.372	.503	0.000	260.8	104.1	91.8	.051
2	.816	.011	.827	.095	.114	.372	.412	.074	269.9	112.3	95.1	.052
3	.780	.011	.790	.177	.225	.371	.396	.145	257.9	111.5	90.9	.050
4	.718	.011	.729	.247	.339	.371	.401	.219	237.9	106.9	83.8	.046
5	.640	.011	.651	.351	.540	.371	.402	.349	212.2	101.7	74.8	.041
6	.735	.011	.745	.434	.583	.370	.248	.376	242.8	117.8	85.5	.047
7	.746	.011	.756	.493	.651	.371	.193	.421	246.4	122.2	86.9	.048
8	.753	.011	.763	.637	.835	.369	.092	.538	248.3	129.7	87.5	.048
9	.637	.011	.648	.709	1.094	.369	.074	.706	210.7	118.1	74.3	.041
10	.696	.011	.707	.694	.982	.370	.035	.634	229.6	125.0	80.9	.045
11	.706	.011	.716	.721	1.006	.369	.024	.649	232.9	127.5	82.1	.045

Table XXI

Pumping Coefficient Data, Model B ($950^{O}F$), M=.047

HOT RIG PERFORMANCE
6 RING DIFFUSER
TUPT: 950

DATE: 20MAR84

DATA TAKEN BY R.W.WHITE

NUMBER OF PRIMARY NOZZLES: 4
PRIMARY NOZZLE DIAMETER: 2.25 INCHES
UPTAKE DIAMETER: 7.51 INCHES
AREA RATIO: 2.5
GAMMA: 1.3556

MIXING STACK LENGTH: 7.122 INCHES
MIXING STACK DIAMETER: 7.122 INCHES
MIXING STACK L/D: 1.5
STANDOFF RATIO: .5
AMBIENT PRESSURE: 29.796 IN HG

NR	PNH IN HG	DELPN IN H2O	TNH DEG F	ROTA	TBURN DEG F	TUPT DEG F	TAMB DEG F	PUPT IN H2O	PPLN IN H2O	SEC AREA SQ IN	P*
1	9.02	2.66	175.9	34.0	1267.0	950.0	64.3	5.09	2.84	0.000	.217
2	8.99	2.66	176.2	34.0	1265.0	951.0	65.4	5.38	2.49	1.767	.191
3	8.97	2.66	176.0	34.0	1264.0	952.0	64.4	5.45	2.19	3.534	.167
4	8.94	2.66	176.3	34.0	1262.0	953.0	63.8	5.85	1.88	5.301	.144
5	9.00	2.66	176.2	34.0	1260.0	953.0	64.4	6.20	1.50	8.443	.115
6	9.00	2.66	176.3	34.0	1266.0	953.0	62.4	6.44	1.22	11.585	.093
7	9.03	2.66	176.3	34.0	1271.0	954.0	64.4	6.50	.97	14.726	.074
8	9.04	2.66	176.3	34.0	1271.0	954.0	62.4	7.17	.47	27.293	.036
9	8.93	2.66	176.3	34.0	1273.0	954.0	62.4	7.29	.27	39.859	.021
10	9.04	2.66	176.1	34.0	1268.0	952.0	63.1	7.35	.15	52.425	.012
11	9.06	2.66	176.2	34.0	1264.0	954.0	62.5	7.34	.11	64.992	.008

NR	WPA LBM/S	WF LBM/S	WP LBM/S	WS LBM/S	W*	T*	P*/T*	W*T**.44	UP FT/S	UM FT/S	UU FT/S	UMACH
1	.731	.011	.742	0.000	0.000	.372	.584	0.000	242.0	96.6	85.2	.047
2	.730	.011	.741	.095	.128	.372	.513	.083	241.8	101.1	85.2	.047
3	.730	.011	.741	.177	.239	.371	.451	.155	241.8	105.1	85.2	.047
4	.730	.011	.740	.247	.334	.371	.389	.216	241.6	108.4	85.1	.047
5	.731	.011	.741	.351	.474	.371	.310	.306	241.6	113.4	85.1	.047
6	.731	.011	.741	.434	.586	.370	.251	.378	241.4	117.3	85.1	.047
7	.731	.011	.741	.493	.665	.371	.200	.430	241.6	120.2	85.1	.047
8	.731	.011	.742	.637	.859	.369	.097	.554	241.3	126.9	85.0	.047
9	.730	.011	.740	.709	.957	.369	.057	.617	240.8	130.1	84.9	.047
10	.731	.011	.742	.694	.936	.370	.031	.605	240.8	129.5	84.9	.047
11	.731	.011	.742	.721	.971	.369	.022	.627	241.2	130.8	85.0	.047

Table XXII

Pumping Coefficient Data, Model B (950^{o}F), M=.036

HOT RIG PERFORMANCE
6 RING DIFFUSER
TUPT: 950

DATE: 20MAR84

DATA TAKEN BY R.W.WHITE

NUMBER OF PRIMARY NOZZLES: 4
PRIMARY NOZZLE DIAMETER: 2.25 INCHES
UPTAKE DIAMETER: 7.51 INCHES
AREA RATIO: 2.5
GAMMA: 1.3556

MIXING STACK LENGTH: 7.122 INCHES
MIXING STACK DIAMETER: 7.122 INCHES
MIXING STACK L/D: 1.5
STANDOFF RATIO: .5
AMBIENT PRESSURE: 29.796 IN HG

NR	PNH IN HG	DELPN IN H2O	TNH DEG F	ROTA	TBURN DEG F	TUPT DEG F	TAMB DEG F	PUPT IN H2O	PPLN IN H2O	SEC AREA SQ IN	P*
1	12.44	1.55	173.9	25.0	1217.0	952.0	65.5	2.61	1.58	0.000	.198
2	12.47	1.70	173.6	25.0	1216.0	953.0	63.7	2.87	1.37	1.767	.154
3	12.54	1.02	173.5	25.0	1216.0	952.0	64.6	2.93	1.20	3.534	.236
4	12.44	1.40	173.7	25.0	1218.0	953.0	65.9	3.09	1.03	5.301	.145
5	12.40	1.34	173.9	25.0	1213.0	951.0	65.3	3.27	.84	8.443	.123
6	12.53	1.38	173.7	25.0	1212.0	950.0	64.3	3.43	.68	11.585	.097
7	12.55	1.29	173.4	25.0	1214.0	953.0	62.9	3.65	.55	14.726	.083
8	12.44	1.97	173.4	25.0	1217.0	953.0	64.9	3.88	.26	27.293	.025
9	12.49	1.14	173.4	25.0	1210.0	950.0	64.5	3.94	.12	39.859	.021
10	12.48	2.14	173.0	25.0	1209.0	950.0	66.3	3.97	.08	52.425	.007
11	12.47	.81	173.4	25.0	1210.0	953.0	66.6	4.00	.03	64.992	.008

NR	WPA LBM/S	WF LBM/S	WP LBM/S	WS LBM/S	W*	T*	P*/T*	W*T**.44	UP FT/S	UM FT/S	UU FT/S	UMACH
1	.573	.007	.580	0.000	0.000	.372	.533	0.000	188.9	75.4	67.1	.037
2	.603	.007	.610	.070	.115	.370	.416	.074	198.8	82.7	70.6	.039
3	.456	.007	.463	.131	.284	.371	.636	.184	150.6	66.5	53.5	.030
4	.542	.007	.549	.183	.333	.372	.389	.215	178.6	80.1	63.5	.035
5	.528	.007	.535	.262	.489	.372	.331	.316	174.0	82.1	61.8	.034
6	.539	.007	.546	.325	.595	.372	.261	.385	177.3	86.4	63.0	.035
7	.520	.007	.526	.370	.703	.370	.224	.454	171.2	86.1	60.9	.034
8	.653	.007	.660	.470	.713	.371	.067	.461	214.6	108.3	76.3	.042
9	.485	.007	.492	.471	.959	.372	.057	.621	159.4	86.3	56.7	.031
10	.683	.007	.690	.489	.709	.373	.018	.460	223.7	112.9	79.5	.044
11	.400	.007	.406	.384	.944	.373	.021	.611	132.0	71.2	46.9	.026

Table XXIII

Pumping Coefficient Data, Model B (950^{o}F), M=.036

HOT RIG PERFORMANCE
6 RING DIFFUSER
TUPT: 950

DATE: 20MAR84

DATA TAKEN BY R.W.WHITE

NUMBER OF PRIMARY NOZZLES: 4
PRIMARY NOZZLE DIAMETER: 2.25 INCHES
UPTAKE DIAMETER: 7.51 INCHES
AREA RATIO: 2.5
GAMMA: 1.3556

MIXING STACK LENGTH: 7.122 INCHES
MIXING STACK DIAMETER: 7.122 INCHES
MIXING STACK L/D: 1.5
STANDOFF RATIO: .5
AMBIENT PRESSURE: 29.796 IN HG

NR	PNH IN HG	DELPN IN H2O	TNH DEG F	ROTA	TBURN DEG F	TUPT DEG F	TAMB DEG F	PUPT IN H2O	PPLN IN H2O	SEC AREA SQ IN	P*
1	12.44	1.43	173.9	25.0	1217.0	952.0	65.5	2.61	1.58	0.000	.216
2	12.47	1.43	173.6	25.0	1216.0	953.0	63.7	2.87	1.37	1.767	.186
3	12.54	1.43	173.5	25.0	1216.0	952.0	64.6	2.93	1.20	3.534	.163
4	12.44	1.43	173.7	25.0	1218.0	953.0	65.9	3.09	1.03	5.301	.141
5	12.40	1.43	173.9	25.0	1213.0	951.0	65.3	3.27	.84	8.443	.115
6	12.53	1.43	173.7	25.0	1212.0	950.0	64.3	3.43	.68	11.585	.093
7	12.55	1.43	173.4	25.0	1214.0	953.0	62.9	3.65	.55	14.726	.074
8	12.44	1.43	173.4	25.0	1217.0	953.0	64.9	3.88	.26	27.293	.035
9	12.49	1.43	173.4	25.0	1210.0	950.0	64.5	3.94	.12	39.859	.017
10	12.48	1.43	173.0	25.0	1209.0	950.0	66.3	3.97	.08	52.425	.010
11	12.47	1.43	173.4	25.0	1210.0	953.0	66.6	4.00	.03	64.992	.004

NR	WPA LBM/S	WF LBM/S	WP LBM/S	WS LBM/S	W*	T*	P*/T*	W*T**.44	UP FT/S	UM FT/S	UU FT/S	UMACH
1	.548	.007	.555	0.000	0.000	.372	.580	0.000	181.0	72.3	64.3	.035
2	.549	.007	.556	.070	.126	.370	.501	.082	181.1	75.7	64.4	.036
3	.549	.007	.556	.131	.236	.371	.440	.153	181.1	78.6	64.4	.036
4	.549	.007	.555	.183	.329	.372	.380	.213	180.9	81.0	64.3	.035
5	.548	.007	.555	.262	.471	.372	.308	.305	180.4	84.7	64.1	.035
6	.549	.007	.556	.325	.585	.372	.251	.378	180.6	87.7	64.2	.035
7	.549	.007	.556	.370	.665	.370	.201	.429	181.0	90.0	64.3	.035
8	.549	.007	.556	.470	.847	.371	.095	.548	180.6	94.8	64.2	.035
9	.549	.007	.556	.471	.848	.372	.045	.549	180.3	94.7	64.1	.035
10	.549	.007	.556	.489	.880	.373	.028	.570	180.3	95.6	64.1	.035
11	.549	.007	.556	.384	.690	.373	.011	.447	180.6	90.6	64.2	.035

Table XXIV

Pumping Coefficient Data, Model B (950°F), M=.032

HOT RIG PERFORMANCE
6 RING DIFFUSER
TUPT: 950

DATE: 21MAR84

DATA TAKEN BY R.W.WHITE

NUMBER OF PRIMARY NOZZLES: 4
PRIMARY NOZZLE DIAMETER: 2.25 INCHES
UPTAKE DIAMETER: 7.51 INCHES
AREA RATIO: 2.5
GAMMA: 1.3556

MIXING STACK LENGTH: 7.122 INCHES
MIXING STACK DIAMETER: 7.122 INCHES
MIXING STACK L/D: 1.5
STANDOFF RATIO: .5
AMBIENT PRESSURE: 29.98 IN HG

NR	PNH IN HG	DELPN IN H2O	TNH DEG F	ROTA	TBURN DEG F	TUPT DEG F	TAMB DEG F	PUPT IN H2O	PPLN IN H2O	SEC AREA SQ IN	P*
1	1.45	1.63	172.6	21.0	1201.0	951.0	67.3	2.72	1.25	0.000	.207
2	1.48	1.66	172.5	21.0	1200.0	950.0	66.0	2.84	1.09	1.767	.178
3	1.49	1.63	172.9	21.0	1201.0	952.0	66.4	2.98	.97	3.534	.161
4	1.50	1.63	173.1	21.0	1202.0	952.0	67.3	3.10	.85	5.301	.141
5	1.51	1.32	173.6	21.0	1190.0	952.0	67.6	3.24	.64	8.443	.133
6	1.51	1.53	173.0	21.0	1190.0	951.0	67.0	3.45	.52	11.585	.092
7	1.53	1.66	173.3	21.0	1190.0	952.0	66.5	3.47	.44	14.726	.072
8	1.52	1.58	173.7	21.0	1191.0	952.0	67.5	3.68	.20	27.293	.034
9	1.54	1.43	173.6	21.0	1193.0	953.0	67.3	3.74	.12	39.859	.023
10	1.54	1.76	173.7	21.0	1191.0	951.0	67.9	3.81	.06	52.425	.009
11	1.54	1.52	173.6	21.0	1188.0	950.0	66.4	3.78	.05	64.992	.008

NR	WPA LBM/S	WF LBM/S	WP LBM/S	WS LBM/S	W*	T*	P*/T*	W*T**.44	UP FT/S	UM FT/S	UU FT/S	UMACH
1	.501	.005	.506	0.000	0.000	.374	.555	0.000	163.7	65.3	58.2	.032
2	.506	.005	.512	.063	.123	.373	.478	.080	165.3	69.0	58.8	.032
3	.501	.005	.506	.118	.234	.373	.433	.151	163.8	71.1	58.2	.032
4	.501	.005	.506	.166	.328	.373	.379	.212	163.7	73.4	58.2	.032
5	.447	.005	.452	.229	.506	.374	.356	.328	146.1	69.4	52.0	.029
6	.486	.005	.491	.283	.576	.373	.245	.373	158.5	76.9	56.3	.031
7	.506	.005	.512	.332	.649	.373	.192	.420	165.3	81.9	58.8	.032
8	.493	.005	.499	.412	.826	.373	.091	.535	160.9	84.1	57.2	.032
9	.467	.005	.472	.472	.999	.373	.062	.647	152.4	83.5	54.2	.030
10	.524	.005	.529	.438	.829	.374	.025	.537	170.6	89.2	60.7	.033
11	.483	.005	.488	.471	.965	.373	.022	.626	157.3	85.4	56.0	.031

Table XXV

Pumping Coefficient Data, Model B (950^{o}F), M=.032

HOT RIG PERFORMANCE
6 RING DIFFUSER
TUPT: 950

DATE: 21MAR84

DATA TAKEN BY R.W.WHITE

NUMBER OF PRIMARY NOZZLES: 4
PRIMARY NOZZLE DIAMETER: 2.25 INCHES
UPTAKE DIAMETER: 7.51 INCHES
AREA RATIO: 2.5
GAMMA: 1.3556

MIXING STACK LENGTH: 7.122 INCHES
MIXING STACK DIAMETER: 7.122 INCHES
MIXING STACK L/D: 1.5
STANDOFF RATIO: .5
AMBIENT PRESSURE: 29.98 IN HG

NR	PNH IN HG	DELPN IN H2O	TNH DEG F	ROTA	TBURN DEG F	TUPT DEG F	TAMB DEG F	PUPT IN H2O	PPLN IN H2O	SEC AREA SQ IN	P*
1	1.45	1.58	172.6	21.0	1201.0	951.0	67.3	2.72	1.25	0.000	.214
2	1.48	1.58	172.5	21.0	1200.0	950.0	66.0	2.84	1.09	1.767	.188
3	1.49	1.58	172.9	21.0	1201.0	952.0	66.4	2.98	.97	3.534	.167
4	1.50	1.58	173.1	21.0	1202.0	952.0	67.3	3.10	.85	5.301	.146
5	1.51	1.58	173.6	21.0	1190.0	952.0	67.6	3.24	.64	8.443	.110
6	1.51	1.58	173.0	21.0	1190.0	951.0	67.0	3.45	.52	11.585	.089
7	1.53	1.58	173.3	21.0	1190.0	952.0	66.5	3.47	.44	14.726	.076
8	1.52	1.58	173.7	21.0	1191.0	952.0	67.5	3.68	.20	27.293	.034
9	1.54	1.58	173.6	21.0	1193.0	953.0	67.3	3.74	.12	39.859	.021
10	1.54	1.58	173.7	21.0	1191.0	951.0	67.9	3.81	.06	52.425	.010
11	1.54	1.58	173.6	21.0	1188.0	950.0	66.4	3.78	.05	64.992	.008

NR	WPA LBM/S	WF LBM/S	WP LBM/S	WS LBM/S	W*	T*	P*/T*	W*T**.44	UP FT/S	UM FT/S	UU FT/S	UMACH
1	.492	.005	.498	0.000	0.000	.374	.574	0.000	160.9	64.3	57.2	.032
2	.493	.005	.498	.063	.126	.373	.504	.082	160.9	67.2	57.2	.032
3	.493	.005	.498	.118	.238	.373	.448	.154	161.0	70.0	57.3	.032
4	.493	.005	.498	.166	.333	.373	.392	.216	161.0	72.3	57.2	.032
5	.493	.005	.498	.229	.460	.374	.294	.298	160.9	75.3	57.2	.032
6	.493	.005	.498	.283	.568	.373	.238	.368	160.8	77.8	57.2	.032
7	.493	.005	.498	.332	.667	.373	.203	.432	160.9	80.2	57.2	.032
8	.493	.005	.498	.412	.827	.373	.091	.536	160.7	84.0	57.2	.032
9	.493	.005	.498	.472	.947	.373	.056	.614	160.9	86.9	57.2	.032
10	.493	.005	.498	.438	.880	.374	.028	.571	160.6	85.2	57.1	.032
11	.493	.005	.498	.471	.946	.373	.021	.613	160.5	86.7	57.1	.032

Table XXVI

Pumping Coefficient Data, Model B (950^{o}F), M=.029

HOT RIG PERFORMANCE
6 RING DIFFUSER
TUPT: 950

DATE: 21MAR84

DATA TAKEN BY R.W.WHITE

NUMBER OF PRIMARY NOZZLES: 4
PRIMARY NOZZLE DIAMETER: 2.25 INCHES
UPTAKE DIAMETER: 7.51 INCHES
AREA RATIO: 2.5
GAMMA: 1.3556

MIXING STACK LENGTH: 7.122 INCHES
MIXING STACK DIAMETER: 7.122 INCHES
MIXING STACK L/D: 1.5
STANDOFF RATIO: .5
AMBIENT PRESSURE: 29.89 IN HG

NR	PNH IN HG	DELPN IN H2O	TNH DEG F	ROTA	TBURN DEG F	TUPT DEG F	TAMB DEG F	PUPT IN H2O	PPLN IN H2O	SEC AREA SQ IN	P*
1	1.25	1.43	171.0	20.0	1217.0	950.0	67.6	2.33	1.05	0.000	.203
2	1.26	1.34	170.9	20.0	1216.0	952.0	66.4	2.42	.93	1.767	.191
3	1.27	1.31	171.1	20.0	1218.0	953.0	66.4	2.54	.84	3.534	.177
4	1.27	1.53	170.7	20.0	1216.0	952.0	67.0	2.58	.73	5.301	.130
5	1.29	1.32	170.7	20.0	1217.0	953.0	66.8	2.75	.53	8.443	.111
6	1.30	1.43	171.2	20.0	1216.0	952.0	68.4	2.90	.46	11.585	.088
7	1.28	1.37	171.4	20.0	1215.0	952.0	66.9	2.98	.35	14.726	.071
8	1.28	1.37	170.6	20.0	1214.0	951.0	66.2	3.15	.18	27.293	.037
9	1.31	1.40	170.9	20.0	1216.0	952.0	66.9	3.28	.11	39.859	.021
10	1.31	1.29	171.2	20.0	1218.0	954.0	66.4	3.28	.08	52.425	.016
11	1.32	1.32	171.4	20.0	1216.0	953.0	66.5	3.37	.03	64.992	.006

NR	WPA LBM/S	WF LBM/S	WP LBM/S	WS LBM/S	W*	T*	P*/T*	W*T**.44	UP FT/S	UM FT/S	UU FT/S	UMACH
1	.465	.005	.470	0.000	0.000	.374	.542	0.000	152.1	60.7	54.2	.030
2	.448	.005	.453	.058	.127	.373	.514	.082	147.0	61.5	52.3	.029
3	.442	.005	.447	.110	.245	.372	.475	.159	145.2	63.2	51.7	.029
4	.484	.005	.489	.153	.314	.373	.348	.204	158.4	70.7	56.4	.031
5	.446	.005	.451	.209	.463	.373	.298	.300	146.1	68.4	52.0	.029
6	.465	.005	.470	.265	.563	.374	.235	.366	152.2	73.6	54.2	.030
7	.454	.005	.459	.295	.644	.373	.189	.417	148.5	73.5	52.9	.029
8	.454	.005	.459	.395	.861	.373	.099	.558	148.5	78.3	52.9	.029
9	.460	.005	.465	.441	.949	.373	.056	.615	150.4	81.3	53.5	.030
10	.440	.005	.445	.490	1.102	.372	.044	.713	144.1	81.1	51.3	.028
11	.446	.005	.450	.384	.853	.372	.017	.552	145.9	76.7	51.9	.029

Table XXVII

Pumping Coefficient Data, Model B ($950^{o}F$), M=.029

HOT RIG PERFORMANCE
6 RING DIFFUSER
TUPT: 950

DATE: 21MAR84

DATA TAKEN BY R.W.WHITE

NUMBER OF PRIMARY NOZZLES: 4
PRIMARY NOZZLE DIAMETER: 2.25 INCHES
UPTAKE DIAMETER: 7.51 INCHES
AREA RATIO: 2.5
GAMMA: 1.3556

MIXING STACK LENGTH: 7.122 INCHES
MIXING STACK DIAMETER: 7.122 INCHES
MIXING STACK L/D: 1.5
STANDOFF RATIO: .5
AMBIENT PRESSURE: 29.89 IN HG

NR	PNH IN HG	DELPN IN H2O	TNH DEG F	ROTA	TBURN DEG F	TUPT DEG F	TAMB DEG F	PUPT IN H2O	PPLN IN H2O	SEC AREA SQ IN	P*
1	1.25	1.37	171.0	20.0	1217.0	950.0	67.6	2.33	1.05	0.000	.212
2	1.26	1.37	170.9	20.0	1216.0	952.0	66.4	2.42	.93	1.767	.186
3	1.27	1.37	171.1	20.0	1218.0	953.0	66.4	2.54	.84	3.534	.167
4	1.27	1.37	170.7	20.0	1216.0	952.0	67.0	2.58	.73	5.301	.146
5	1.29	1.37	170.7	20.0	1217.0	953.0	66.8	2.75	.53	8.443	.107
6	1.30	1.37	171.2	20.0	1216.0	952.0	68.4	2.90	.46	11.585	.092
7	1.28	1.37	171.4	20.0	1215.0	952.0	66.9	2.98	.35	14.726	.070
8	1.28	1.37	170.6	20.0	1214.0	951.0	66.2	3.15	.18	27.293	.037
9	1.31	1.37	170.9	20.0	1216.0	952.0	66.9	3.28	.11	39.859	.021
10	1.31	1.37	171.2	20.0	1218.0	954.0	66.4	3.28	.08	52.425	.015
11	1.32	1.37	171.4	20.0	1216.0	953.0	66.5	3.37	.03	64.992	.006

NR	WPA LBM/S	WF LBM/S	WP LBM/S	WS LBM/S	W*	T*	P*/T*	W*T**.44	UP FT/S	UM FT/S	UU FT/S	UMACH
1	.455	.005	.460	0.000	0.000	.374	.565	0.000	148.9	59.4	53.0	.029
2	.455	.005	.460	.058	.126	.373	.499	.081	149.1	62.3	53.1	.029
3	.455	.005	.460	.110	.238	.372	.450	.154	149.2	64.8	53.1	.029
4	.455	.005	.460	.153	.334	.373	.393	.216	149.1	66.9	53.1	.029
5	.455	.005	.460	.209	.454	.373	.286	.294	149.2	69.6	53.1	.029
6	.455	.005	.460	.265	.576	.374	.246	.374	149.0	72.3	53.1	.029
7	.455	.005	.460	.295	.642	.373	.189	.416	148.9	73.7	53.0	.029
8	.455	.005	.460	.395	.859	.373	.098	.557	148.8	78.4	53.0	.029
9	.455	.005	.460	.441	.958	.373	.057	.621	148.9	80.7	53.0	.029
10	.455	.005	.460	.490	1.066	.372	.041	.690	149.1	83.1	53.1	.029
11	.455	.005	.460	.384	.835	.372	.016	.541	148.9	78.0	53.0	.029

Table XXVIII

Pumping Coefficient Data, Model B (950^{O}F), M=.024

HOT RIG PERFORMANCE
6 RING DIFFUSER
TUPT: 950

DATE: 21MAR84

DATA TAKEN BY R.W.WHITE

NUMBER OF PRIMARY NOZZLES: 4
PRIMARY NOZZLE DIAMETER: 2.25 INCHES
UPTAKE DIAMETER: 7.51 INCHES
AREA RATIO: 2.5
GAMMA: 1.3556

MIXING STACK LENGTH: 7.122 INCHES
MIXING STACK DIAMETER: 7.122 INCHES
MIXING STACK L/D: 1.5
STANDOFF RATIO: .5
AMBIENT PRESSURE: 29.98 IN HG

NR	PNH IN HG	DELPN IN H2O	TNH DEG F	ROTA	TBURN DEG F	TUPT DEG F	TAMB DEG F	PUPT IN H2O	PPLN IN H2O	SEC AREA SQ IN	P*
1	.95	.99	169.1	17.0	1204.0	950.0	68.1	1.95	.77	0.000	.228
2	.94	.96	169.3	17.0	1200.0	950.0	65.5	2.04	.67	1.767	.203
3	.94	1.00	169.3	17.0	1203.0	951.0	68.8	2.14	.59	3.534	.172
4	.94	1.06	169.2	17.0	1208.0	952.0	67.3	2.20	.50	5.301	.136
5	.97	.91	169.1	17.0	1207.0	951.0	65.9	2.28	.39	8.443	.127
6	.98	1.03	169.1	17.0	1210.0	952.0	67.8	2.39	.32	11.585	.089
7	.97	.91	169.0	17.0	1208.0	952.0	66.1	2.45	.27	14.726	.088
8	.98	1.02	168.9	17.0	1203.0	950.0	67.9	2.58	.14	27.293	.039
9	.98	.96	168.9	17.0	1206.0	952.0	66.8	2.61	.06	39.859	.018
10	.99	1.00	168.2	17.0	1204.0	951.0	67.3	2.66	.05	52.425	.013
11	.99	.84	168.4	17.0	1203.0	950.0	67.3	2.63	.03	64.992	.011

NR	WPA LBM/S	WF LBM/S	WP LBM/S	WS LBM/S	W*	T*	P*/T*	W*T**.44	UP FT/S	UM FT/S	UU FT/S	UMACH
1	.377	.004	.381	0.000	0.000	.374	.610	0.000	123.0	49.1	43.9	.024
2	.371	.004	.374	.049	.131	.373	.546	.085	120.8	50.6	43.1	.024
3	.381	.004	.384	.092	.240	.375	.459	.156	124.1	54.0	44.2	.024
4	.393	.004	.397	.127	.321	.373	.363	.208	128.3	57.3	45.7	.025
5	.361	.004	.364	.180	.495	.373	.340	.320	117.6	55.6	42.0	.023
6	.387	.004	.391	.222	.568	.374	.239	.368	126.2	61.1	45.0	.025
7	.361	.004	.365	.262	.718	.372	.235	.465	117.7	59.5	42.0	.023
8	.384	.004	.388	.342	.883	.374	.104	.573	125.0	66.4	44.6	.025
9	.371	.004	.375	.334	.890	.373	.050	.577	120.9	64.3	43.1	.024
10	.381	.004	.385	.380	.987	.374	.035	.640	124.1	67.8	44.3	.024
11	.344	.004	.347	.385	1.107	.374	.029	.718	111.9	63.2	39.9	.022

Table XXIX

Pumping Coefficient Data, Model B (950^{O}F), M=.024

HOT RIG PERFORMANCE
6 RING DIFFUSER
TUPT: 950

DATE: 21MAR84

DATA TAKEN BY R.W.WHITE

NUMBER OF PRIMARY NOZZLES: 4
PRIMARY NOZZLE DIAMETER: 2.25 INCHES
UPTAKE DIAMETER: 7.51 INCHES
AREA RATIO: 2.5
GAMMA: 1.3556

MIXING STACK LENGTH: 7.122 INCHES
MIXING STACK DIAMETER: 7.122 INCHES
MIXING STACK L/D: 1.5
STANDOFF RATIO: .5
AMBIENT PRESSURE: 29.98 IN HG

NR	PNH IN HG	DELPN IN H2O	TNH DEG F	ROTA	TBURN DEG F	TUPT DEG F	TAMB DEG F	PUPT IN H2O	PPLN IN H2O	SEC AREA SQ IN	P*
1	.95	.97	169.1	17.0	1204.0	950.0	68.1	1.95	.77	0.000	.233
2	.94	.97	169.3	17.0	1200.0	950.0	65.5	2.04	.67	1.767	.200
3	.94	.97	169.3	17.0	1203.0	951.0	68.8	2.14	.59	3.534	.178
4	.94	.97	169.2	17.0	1208.0	952.0	67.3	2.20	.50	5.301	.150
5	.97	.97	169.1	17.0	1207.0	951.0	65.9	2.28	.39	8.443	.118
6	.98	.97	169.1	17.0	1210.0	952.0	67.8	2.39	.32	11.585	.096
7	.97	.97	169.0	17.0	1208.0	952.0	66.1	2.45	.27	14.726	.082
8	.98	.97	168.9	17.0	1203.0	950.0	67.9	2.58	.14	27.293	.041
9	.98	.97	168.9	17.0	1206.0	952.0	66.8	2.61	.06	39.859	.018
10	.99	.97	168.2	17.0	1204.0	951.0	67.3	2.66	.05	52.425	.014
11	.99	.97	168.4	17.0	1203.0	950.0	67.3	2.63	.03	64.992	.009

NR	WPA LBM/S	WF LBM/S	WP LBM/S	WS LBM/S	W*	T*	P*/T*	W*T**.44	UP FT/S	UM FT/S	UU FT/S	UMACH
1	.374	.004	.377	0.000	0.000	.374	.622	0.000	121.8	48.6	43.5	.024
2	.374	.004	.377	.049	.130	.373	.537	.084	121.8	51.0	43.4	.024
3	.374	.004	.377	.092	.244	.375	.476	.159	121.8	53.1	43.5	.024
4	.374	.004	.377	.127	.338	.373	.402	.219	121.9	54.8	43.5	.024
5	.374	.004	.378	.180	.478	.373	.317	.309	121.8	57.3	43.5	.024
6	.374	.004	.378	.222	.588	.374	.256	.381	121.9	59.4	43.5	.024
7	.374	.004	.378	.262	.693	.372	.219	.449	121.9	61.2	43.5	.024
8	.374	.004	.378	.342	.906	.374	.110	.588	121.7	65.1	43.4	.024
9	.374	.004	.378	.334	.883	.373	.049	.572	121.9	64.7	43.5	.024
10	.374	.004	.378	.380	1.005	.374	.037	.652	121.9	66.9	43.5	.024
11	.374	.004	.378	.385	1.017	.374	.024	.660	121.8	67.1	43.4	.024

Table XXX

Pumping Coefficient vs Mach Number Data

Mach Number	Pumping Coefficient
TUPT = 175	
.06	.51
.058	.52
.048	.52
.036	.48
.027	.61
TUPT = 950	
.06	.60
.053	.64
.047	.67
.036	.68
.032	.70
.029	.68
.024	.69

Table XXXI

Exit Plane Temperature Profile (^{O}F)

Radial Position(in)	M=.06	M=.053	M=.047	M=.036	M=.024
-4.25	92	85	79	84	86
-4.0	205	190	186	190	229
-3.75	275	263	260	266	310
-3.5	342	332	337	339	395
-3.25	370	380	384	386	426
-3.0	434	420	417	422	458
-2.75	445	440	437	440	472
-2.5	464	458	452	460	490
-2.25	484	477	470	473	497
-2.0	493	493	486	492	511
-1.75	512	503	498	510	518
-1.5	525	521	516	520	530
-1.25	540	536	533	542	546
-1.0	550	547	544	543	553
-.75	562	558	554	553	562
-.5	575	567	566	560	571
-.25	579	573	571	570	578
0	574	570	573	575	578
0	575	571	573	574	578
.25	577	572	572	570	578
.5	573	568	566	561	569
.75	560	557	553	554	561
1.0	550	549	543	544	554
1.25	538	535	531	540	547
1.5	523	520	515	519	531
1.75	509	500	497	511	517
2.0	490	492	487	493	509
2.25	487	476	471	472	498
2.5	463	459	451	461	489
2.75	447	442	435	439	471
3.0	430	419	415	421	454
3.25	370	381	382	387	425
3.5	337	333	336	337	394
3.75	270	264	259	265	309
4.0	200	191	185	191	230
4.25	92	85	79	84	86

Table XXXII

Mixing Stack Type K Thermocouple Data (^{o}F)

TUPT = 950

Thermocouple #	M=.06	M=.053	M=.047	M=.036	M=.024
1	288	286	277	273	283
2	145	147	145	150	190
3	251	247	243	243	287
4	302	295	292	288	310
5	127	126	124	126	125
6	346	342	335	334	341
8	272	304	346	346	345
9	307	305	304	307	308
10	135	138	137	142	180
11	196	194	186	188	189
12	62	62	62	64	64

Table XXXIII

Shroud and Diffuser Ring External Temperatures (^{O}F)

TUPT = 950

Location		M=.06	M=.053	M=.047	M=.036	M=.024
Diffuser Ring	1	72.70	72.44	71.64	75.83	80.26
	2	72.48	72.17	71.24	74.69	78.51
	3	83.62	83.36	83.25	85.98	90.79
	4	79.99	79.65	79.29	82.75	87.15
	6	70.09	69.03	69.74	71.82	73.76
	6A	69.52	68.49	68.63	71.24	73.02
	6B	69.47	69.21	68.68	71.21	74.02
Shroud (X/D)						
1.068		143.78	144.68	144.76	151.68	159.57
1.068		89.2	89.7	88.6	89.8	90.3
.750		84.93	84.93	84.63	89.49	97.91
.688		80.3	80.5	80.4	85.4	93.2
.625		74.55	74.51	73.98	78.11	87.49
.563		83.2	84.5	83.1	88.3	97.6
.438		87.4	88.7	87.3	92.5	102.6
.375		94.21	95.15	94.68	99.92	109.19
.313		88.2	90.3	89.6	94.3	103.6
.188		93.4	95.6	94.2	100.3	108.8
.125		100.44	102.07	101.77	107.49	116.97
.063		96.8	98.2	97.2	103.4	110.7

Table XXXIV

Mixing Stack Pressures

(in H_2O ref. to atmospheric)

Pressure Tap	M=.06	M=.053	M=.047	M=.036	M=.024
A	-2.535	-2.171	-2.125	-1.958	-1.852
B	-2.551	-2.459	-2.292	-2.109	-1.897
C	-3.813	-3.128	-2.778	-2.399	-2.049
D	-2.399	-2.095	-2.004	-1.882	-1.806
E	-2.551	-2.141	-2.111	-1.944	-1.852
F	-3.703	-3.036	-2.732	-2.368	-2.065
G	-2.732	-2.322	-2.262	-2.049	-1.897
H	-2.475	-2.095	-2.095	-1.944	-1.837

APPENDIX A

DEC COMPUTER UTILIZATION

Walsh [Ref. 14] discussed the inability to utilize equipment given to the Mechanical Engineering Department as part of a research grant. Four VT103 computers and four DECWRITER IV line printers were received. Walsh was unable to utilize the computer to "talk" over in IEEE-488 Standard data bus despite repeated software efforts. Consequently the bus control card, called the IBVII A, was determined to be faulty and returned to DEC for repair.

This research attempted to utilize this equipment following repair of the card. References 15 and 16 detail specific guidelines for the user to follow in creating the bus handling routines necessary to communicate over the IEEE-488 bus. These instructions were followed explicitly. Upon running a DEC system test an error message was noted that stated that the IBV11A was not physically present in the computer.

Utilizing an Octal Debugging Technique (ODT) peculiar to DEC computers the control status register of the IBV11A was queried to determine card location. It was possible to read from and write to this location and therefore the card was assumed valid.

Another attempt to rebuild the bus handling routine proved futile, with the same error message appearing. The

RT-11 Team, a reference group employed by DEC, was contacted and the problem discussed. The team stated that the IBV11A was one of DEC's more obscure products and in-house knowledge limited. No solutions other than those already attempted were suggested. Contact was made with the sales representative who sold the board to the Mechanical Engineering Department to no avail.

It is suspected that the inability of the card to operate properly is software related. In order to exactly determine this, the bus handling routines need examination using ODT to determine the exact flow of data between registers. This is a time consuming process and was not attempted.

APPENDIX B

GAS GENERATOR OPERATION

I. PRIMARY AIR COMPRESSOR OPERATION

Primary air flow is supplied by a Carrier three stage centrifugal air compressor located in Building 230. A Western Gear Model 95HSA speed increasing gearbox connects the compressor to a 300 horsepower General Electric induction motor. Figure 16 depicts the air compressor. Cooling water is shared with a Sullivan compressor also located in Building 230.

Cooling water cools the system lube oil in a closed loop oil to fresh water heat exchanger. Lube oil is supplied by either an electric auxiliary lube oil pump or an attached lube oil pump, both of which use a common external pump.

The compressor lube oil system should be started approximately one hour prior to compressor light off. This allows adequate pre-lubrication, warms the oil slightly, and decreases starting loads. This is critical as the compressor operates near breaker capacity during start up. Should the substation breaker trip the Public Works Trouble Desk should be notified in order that base electricians can reset the breaker.

At times it is required to operate the compressor daily. The auxiliary lube oil pump may be left running overnight to facilitate timely startup of the compressor.

About one hour after start up the compressor reaches steady-state operation and provides inlet air at 170-190°F. It is recommended that the inlet air temperature be stabilized prior to gas generator lightoff to ensure stable operation during individual data runs and decrease the number of control adjustments necessary at each system operation point. The following sequence is recommended:

A) Verify that the lube oil level in the external sump is within four inches within the top of the sight glass.

B) Start the auxiliary lube oil pump by placing the "hand-off-automatic" switch in the "hand" position. Check for system leaks and verify lube oil pressure of about 30 psig.

C) Wait until compressor bearing temperature reaches about 70°F.

D) Line up the gas generator for operation.

   1) Open the two pressure isolation valves (Fig. 13).

   2) Ensure that the main air supply butterfly valve is closed.

   3) Open the inlet air bypass globe valve two to three turns (Fig. 13).

   4) Open the manually operated 4 inch butterfly isolation valve (Fig. 14).

   5) Energize the main control panel (Fig. 11) and fully open the electrically operated burner air and bypass air valves.

6) Ensure that the gas generator exhaust area is clear.

E) Start the air compressor cooling system:

1) Ensure that the water level in the cooling tower is level with that of the inlet line.

2) Vent the cooling water pump casing using the petcock on the suction side of the pump.

3) Close valve "A" to the Sullivan compressor and open valve "B" to the Carrier compressor.

4) Start the cooling water pump and fan which are interlocked and must be started in that order.

5) Verify proper water circulation by visually inspecting the drip lattice.

F) Open the air compressor air cooling bank drain valve (Fig. 18).

G) Fully close the compressor air suction valve (indicator vertical) (Fig. 17).

WARNING WARNING WARNING WARNING WARNING WARNING

Hazardous noise is produced when the compressor is running; all personnel in the vicinity should wear adequate aural protection.

H) Start the air compressor noticing the automatic two stage starter circuit.

I) After the compressor is fully up to speed secure the auxiliary lube oil pump by placing the switch in the "automatic" position. Verify lube oil pressure of 24-30 psig. The auxiliary pump will automatically start should pressure drop to 12 psig.

J) Slowly open the suction valve until the indicator is horizontal. Air is now being supplied to the gas generator. Bypass air for other experiments is exhausted to the atmosphere at the rear of building 230. If required this flow can be secured by closing the isolation valve located inside the addition to the back of building 230.

K) Periodically check compressor operation to ensure the following operating points:

Attached lube oil pressure	24-30 psig
Lube oil cooler outlet temp	100-105°F (135°F Max)
Compressor bearing temp	140-160°F (180°F Max)
Speed increaser oil temp	120-130°F

II. GAS GENERATOR LIGHT OFF

Approximately one and one half hours after starting the air compressor the gas generator may be lighted off.

A) Fifteen minutes prior to ignition line up the fuel system as follows:

1) Open the fuel tank suction (Fig. 21) and bulkhead isolation (Fig. 22) valves.
2) Close the solenoid operated fuel cutoff valve and close the HP fuel pump manual discharge valve.
3) Open the nozzle box drain valve.
4) Open the fuel control valve (Fig. 23) and if this is the first time the system is being utilized, open the

needle trimmer valve (Fig. 22). If the trimmer valve is not known to be set properly adjust it following the next few steps.

5) Start the fuel supply pump and observe fuel pressure of 14-16 psig.

6) Start the HP fuel pump. With the manual control and needle trimmer valves open system pressure will be about 25-30 psig. With the needle valve properly set the pressure will be 80-90 psig.

7) To set the trimmer valve, open it fully and close the manual control valve. Close the trimmer valve until the HP pump discharge pressure is 350 psig. This sets the trimmer valve and permits operator control of the HP pump discharge pressure over a range of 80-350 psig.

8) To facilitate combustion and ensure a clean light off set the HP pump discharge pressure at 200 psig and allow the fuel to recirculate for 10-15 minutes.

B) The gas generator may be lighted when the inlet air temperature reaches 170°F.

1) Adjust the inlet air bypass valve to achieve a pressure of 54 inches of H_2O at the upstream side of the inlet reducing section (PNH).

2) Open fully the burner air valve. Adjust the cooling air valve until the pressure drop across the U tube is approximately 1.6 inches H_2O. It may be necessary to reduce PNH slightly to achieve this pressure. This

results in pressure drop across the inlet reducing section (DELPH) of about 12 inches H_2O.

3) Open the manual discharge valve.
4) Utilizing the existing LED displays monitor TBURN and TUPT.
5) Clear the gas generator exhaust area.
6) Set the HP fuel pump discharge pressure at 150 psig.
7) Depress and hold down the spring loaded ignitor switch for 10 seconds.
8) Continue to hold down the ignitor switch and open the solenoid operated emergency fuel cutoff valve. Within 6-12 seconds ignition should be observed. If the gas generator fails to ignite close the emergency cutoff valve and release the ignitor. The system should not be restarted until no raw fuel is being expelled from the primary nozzles. Fuel will collect at the base of the secondary plenum below the primary nozzles and should be wiped up prior to restarting the ignition sequence.
9) Release the ignitor switch when ignition is observed.
10) As the burner temperature approaches $1100^{\circ}F$ reduce the fuel pressure to approximately 70-75 psig which stabilizes burner temperature between 1050 and $1150^{\circ}F$.

DO NOT ALLOW TBURN TO EXCEED $1500^{\circ}F$ OR FALL BELOW $1000^{\circ}F$

Stable operation at a desired burner temperature can be achieved by closing the cooling air valve 50 percent.

Should TBURN fall below 1000°F white smoke will appear at the exhaust. Combustion ceases at 800°F. Should this happen IMMEDIATELY secure the solenoid operated emergency cutoff valve. The ignition sequence should then be restarted.

The above sequence leads to stable operation with and uptake temperature of 400-500°F and an uptake Mach number of about 0.07.

DO NOT ALLOW TUPT TO EXCEED 1200°F

11) Close the nozzle box drain valve prior to adjusting the uptake Mach number.

III. TEMPERATURE/MACH NUMBER CONTROL

Control is obtained by sequentially adjusting the uptake temperature (TUPT), inlet air pressure (PNH), and bypass cooling air flow. This process is frustrating at first and requires considerable expertise to master efficiently.

The effect of the bypass cooling air valve depends on the initial position of the valve. If the valve is more than 50 percent open, further opening of the valve increases TBURN, however, the increase in the amount of cooling air negates this and lowers TUPT. When the valve is initially less than 50 percent and especially when it is less than 25 percent open, opening of the valve will raise the uptake temperature despite an increase in cooling air flow. Considering these effects the following adjustment process is recommended:

A) Obtain the desired uptake temperature using the fuel control valve ensuring that the burner temperature stays within the 1000-1300°F range.

B) As TBURN approaches either one of these limits, adjust the bypass cooling air valve or the inlet air valve, depending on the previous operating condition. Key parameters for Mach number control are TUPT, PUPT, and DELPN. Safe combustion is ensured by monitoring TBURN.

C) Once stable operation is achieved with the desired uptake temperature the uptake Mach number (UMACH) should be verified prior to commencing data acquisition. Use the following formula:

$$UMACH = .1037\left(\frac{TUPTR}{\gamma}\right)^{.5} * \left\{\left[\left(\frac{PNH}{13.5717} + B\right) * \frac{DELPN}{TNHR}\right]^{.5} + (.4014 * ROTA - 3.0904)\Big/\left(B + \frac{PUPT}{13.5717}\right)\right\} \quad \text{(eqn B.1)}$$

where

UMACH = uptake Mach number

TUPTR = uptake temperature, R

γ = ratio of specific heats for air,

PNH = inlet air pressure (in H_2O)

B = barometric pressure (in Hg)

DELPN = entrance nozzle pressure drop, (in H_2O)

TNHR = inlet air temperature, R

ROTA = rotameter reading

PUTP = uptake pressure, (in H_2O)

SPECIFIC HEAT VALUES FOR AIR

TUPT (^{o}F)	γ
175	1.3991
650	1.3741
750	1.3677
850	1.3614
950	1.3556

D) Obtain the desired uptake Mach number of adjusting the uptake temperature by varying the combination of inlet globe valve, cooling air valve, and fuel control valve settings.

E) Once the desired Mach number and uptake temperature have been achieved, little control changes are necessary. During pumping coefficient runs slight control changes may be required upon closing the secondary plenum .

IV. SECURING THE SYSTEM

A) Shut down the gas generator by reducing fuel pressure to minimum and immediately secure the emergency solenoid operated fuel cutoff valve.

1) Secure the HP fuel pump.

2) Secure the fuel supply pump.

3) Open the cooling air bypass valve.

4) Open the inlet air bypass valve until PHN is approximately 62 in H_2O.

5) Continue to operate at this point until the uptake temperature falls to approximately the air inlet temperature.

6) Close the fuel system bulkhead and tank isolation valve. Refill the fuel supply reservoir as this prevents condensation within the reservoir. Water or sediment can be stripped via the stripping connection.

B) Once the gas generator has cooled the air compressor may be secured.

1) Close the suction valve.

2) Stop the electric motor.

3) When the oil pressure falls to 20 psig start the auxiliary lube oil pump.

4) Allow the lube oil system to operate until bearing temperatures are below $80^{o}F$.

5) Secure the auxiliary lube oil pump.

6) Secure the cooling water tower fan and cooling water pump.

C) Close the 4 inch butterfly manual isolation valve.

D) Close the inlet bypass globe valve.

E) Open the nozzle box drain valve.

F) Secure the main power panel and secure the data acquisition system.

APPENDIX C

UNCERTAINTY ANALYSIS

Kline and McClintock [Ref. Kline] describe methods of uncertainty analysis which were utilized in the calculation of pumping coefficient uncertainties. Hill [Ref. Hill] formulated the basic uncertainty analysis of the hot flow facility. Staples [Ref. Staples] corrected the analysis for modifications to the fuel measuring equipment. The second order equation suggested by Kline and McClintock is applicable in this research and the results are listed here.

UNCERTAINTY IN MEASURED VALUES

Parameter	Value	Uncertainty
TAMB	541 R	± 1
TUPT	1423 R	± 1
B	28.93 in Hg	± 0.004
DELPN	6.00 in H_2O	± 0.05
PUPT	12.8 in H_2O	± 0.03
ROTA	29	± 0.2
PNH	62.0 in H_2O	± 0.08
TNH	640 R	± 0.3
PPLN	5.3 in H_2O	± 0.02

UNCERTAINTY IN CALCULATED VALUES

P*/T*	± 1.86
W*T**.44	± 1.39

APPENDIX D

DATA ACQUISITION PROGRAM

```
5   REM
10  REM FILE NAME RIGACQT
15  REM WRITTEN BY LT. R. W. WHITE
20  REM NPGS, JANUARY, 1984
25  REM
30  REM PROGRAM DESCRIPTION:
35  REM THIS PROGRAM ALLOWS SEQUENTIAL SCANNING OF A SCANI-
    VALVE BETWEEN PORTS
40  REM SPECIFIED BY THE USER
45  REM TEMPERATURE DATA ACQUISITION IS ALSO PROVIDED.
50  REM THE SCANIVALVE AND THE THERMOCOUPLES ARE ACCESSED
    VIA AN HP 3497 SCANNER.
55  REM
60  REM
65  REM VARIABLES UTILIZED
70  REM L LOW PORT
75  REM H HIGH PORT
80  REM
85  REM
90  REM
95  REM
100 REM
```

```
105 REM
110 REM
115 DIM X(42),Y(20)
120 DISP "ENTER DATE OF RUN      EX 12AUG83"
125 INPUT D$
130 DISP "INPUT RUN NUMBER"
135 INPUT R
140 DISP "DATE OF RUN:",D$,"RUN NUMBER:",R
145 PRINT "DATE OF RUN:",D$
150 PRINT "RUN NUMBER:",R
155 DISP "INPUT BAROMETRIC PRES."
160 INPUT B
165 PRINT "BAR.PRES.:",B,"IN HG"
170 DISP "INPUT ROTAMETER READING"
175 INPUT F
176 DISP "INPUT GAMMA, AIR SPECIFIC HEAT RATIO"
177 INPUT G
180 DISP "INPUT DATA FILE NAME"
185 DISP "FOR PRESS,TYPET,TYPEK"
190 INPUT P$,T$,K$
195 ASSIGN# 1 TO P$
200 ASSIGN# 2 TO T$
205 ASSIGN# 3 TO K$
210 PRINT# 1; D$,R,B
211 PRINT# 1; G
215 PRINT# 2; D$,R,B
```

```
216 PRINT# 2; G
220 PRINT# 3; D$,R,B
221 PRINT# 3; G
225 REM
230 REM LOOP FOR SEC. AIR
235 FOR X=1 TO 12
240 REM
245 PRINT# 1; X
250 PRINT# 2; X
255 PRINT# 3; X
260 S=1
265 REM
270 REM GET S/V PRESSURES
275 DISP "READING S/V"
280 REM INPUT L
290 REM INPUT H
296 REM OUTPUT 709; "SC"
297 REM OUTPUT 709; "AR"
300 FOR I=1 TO 19
305 OUTPUT 709; "DC4,00"
306 FOR J1=1 TO 40
307 NEXT J1
310 OUTPUT 709; "DO4,00"
215 OUTPUT 709; "AI",31
320 ENTER 709; V
325 A=0
```

```
330 OUTPUT 709; "AI20"
335 ENTER 709; Z9
340 IF Z9>=4 THEN 350
345 A=1
350 OUTPUT 709; "AI21"
355 ENTER 709; G
360 IF G>=4 THEN 370
365 A=A+2
370 OUTPUT 709; "AI22"
375 ENTER 709; H
380 IF H>=4 THEN 390
385 A=A+4
390 OUTPUT 709; "AI23"
395 ENTER 709; J
400 IF J>=4 THEN 410
405 A=A+8
410 OUTPUT 709; "AI24"
415 ENTER 709; K
420 IF K>=4 THEN 430
425 A=A+10
430 OUTPUT 709; "AI25"
435 ENTER 709; L
440 IF L>=4 THEN 450
445 A=A+20
450 OUTPUT 709; "AI26"
455 ENTER 709; M
```

```
460 IF M>=4 THEN 470
465 A=A+40
470 DISP "S/V CHNL";A
475 REM S/V LINEAR CALIBRATION
480 V1=1.5663099129
485 V2=15189.9464291
490 P=V1+V*V2
495 DISP P; "IN H2O"
500 PRINT# 1; A,V,P
505 NEXT I
510 OUTPUT 709; "DC4,01"
515 OUTPUT 709; "DO4,01"
520 DISP "READING TYPE T"
525 REM TYPE T
530 Mφ=.1008609
535 M1=25727.94369
540 M2=-767345.8295
545 M3=78025595.81
550 M4=-9247486589
555 M5=697688000000
560 M6=-2.66192E13
565 M7=3.94078E14
570 OUTPUT 709; "SC"
575 OUTPUT 709; "AR"
580 FOR I=0 TO 14
585 OUTPUT 709; "AC", I
```

```
590 ENTER 709; V
595 T=0
600 T=M0+V*(M1+V*(M2+V*(ME+V*(M4+V*(M5+V*(M6+V*M7))))))
605 REM DEG C TO DEG F
610 T=9/5*T+32
615 PRINT# 2; I,V,T
620 DISP I: T
625 NEXT I
630 REM TYPE K
635 N0=.226584602
640 N1=24152.109
645 N2=67233.4284
650 N3=2210340.682
655 N4=-860963914.9
660 N5=48335060000
665 N6=-1.18452E12
670 N7=1.3869E13
675 N8=6.33708E13
680 DISP "READING TYPE K"
685 FOR I=40 TO 55
690 DISP "INPUT TYPE K RDG FROMOLD LED"
695 INPUT K
700 DISP K
705 PRINT# 3; I,K
710 NEXT I
715 DISP "ANOTHER RUN ?"
```

```
720 DISP "ENTER 1(YES) OR 2(NO)"
725 INPUT A
730 IF A=1 THEN 737
735 GOTO 745
737 OUTPUT 709; "AR"
740 NEXT X
745 ASSIGN# 1 TO *
750 ASSIGN# 2 TO *
755 ASSIGN# 3 TO *
760 END
```

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